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THE METAMORPHIC CYCLE

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Katamorphism.—Igneous rocks, when affected by meteoric agencies at and below the weathering surface, tend to become adjusted to their new environment in such a manner that their constituents become distributed as follows:

- Original igneous and crystalline rocks
  - Material removed
    - Carried as solids
      - Mechanical sediments—
        - Shales
        - Sandstones
        - Conglomerates, etc.
    - Carried in solution
      - Chemical sediments—
        - Limestone, etc.
      - Cementing materials
      - Vein-filling materials
      - Mineral matter of the sea
  - Material remaining
    - Weathered rock
    - Residual clays and soils

Fully 97 per cent. of the end-products are sediments included under the general names of shales, sandstones, and limestones. Arkoses, graywackes, conglomerates, etc., containing original complex silicates, may be regarded as intermediate stages of alteration, and may thus be disregarded in a consideration of ultimate products. Of these the shales are by far the dominant sediments, as shown by field observation, by measurement of river loads, and by calculations of the relative proportions of the three sediments necessary most nearly to approximate the composition of the parent rocks. The last method, which is well based, puts the average percentage of shales, derived from the average igneous or crystalline rock, as high as 79 per cent., the sandstones constituting 12 per cent., and the lime-

stones 9 per cent. of the total of these three sediments.[1] Averages of sections made from field observations give uniformly a lower percentage of shales and higher percentage of limestone. An average of twenty-one sections from different parts of the United States shows 30 per cent. of limestone. If the difference of proportion determined by the chemical and field methods is a real one, as inspection of the data used seems to indicate, the significant questions are raised, (1) whether there may not be a concentration of limestones on continental areas, their complementary shales and muds being in the deep sea; or (2) whether limestone may not be concentrated in the upper, observed, part of the lithosphere, because of its known inability to remain in the deep-seated zones of high pressure and temperature. But whether the differences in results reached by the two methods are real or apparent, there is sufficient accordance in the main features of the redistribution of the elements for the purposes of the following discussion.

The changes summarized in the table are destructive or katamorphic (Van Hise) or descensional (Chamberlin and Salisbury). Chemically there is a sundering of complex silicates. The bases, for the most part, go off in solution and are precipitated as oxides, carbonates, sulphides, and even silicates, or remain in solution, a notable instance being sodium chloride. Kaolin develops simultaneously through the hydration in place of the remaining alumina silicates. Neither the free quartz nor other oxides are greatly changed. The mineralogical changes, so far as quantitatively known, may be roughly expressed by a comparison of the minerals of the average parent rock, and of the end-products in above proportion of sediments, as in the following diagram.

Feldspars obviously yield much the largest part of the shales, and a relatively small part comes from the ferromagnesian minerals. Quartz becomes more abundant in the katamorphosed rocks. The quartz of the sandstone may be regarded as corresponding in amount approximately with the free quartz of the igneous rock, indicating that the quartz of the shales is derived largely from the pre-existing feldspars. The minerals of the limestone and allied sediments are

[1] W. J. Mead, "Redistribution of Elements in the Formation of Sedimentary Rocks," *Journal of Geology*, Vol. XV, No. 3, pp. 238 ff.

derived from the bases of the basic feldspars and ferromagnesian minerals.

Physically, katamorphism of igneous rocks to average sediments means a slight increase in average volume of minerals of perhaps 3 per cent., a figure derived by comparing the specific gravities of the

Cementation of Sediments
Shales, sandstone & quartzite, limestone & marble.
Katamorphism producing Slates, Schists, Gneisses & Marble.
Average mineralogical proportions not yet known but approaching those of the igneous rocks more closely than do the sediments.
Feldspars 60%
Ferromagnesian and miscellaneous minerals 28%
Quartz 12%
Average Igneous and Crystalline Rock
Katamorphism producing average Sediments
Sands, largely quartz 11%
Limestone, etc. 9%
Average muds & clays 80%
Kaolin, 20%
Feldspars, 26%
Quartz, 22%
Miscellaneous Minerals, 12%

FIG. 1.—Diagram showing mineralogical redistribution in metamorphism.

minerals of the parent rock with those of the resultant average sediments in the stated proportions. A similar result is obtained by calculating volume-changes from the chemical equations of the common alterations of the rock-making minerals to the minerals of the sediments. Where altered to extreme end-products throughout, such as kaolin, quartz, and calcite, there is an average volume-increase of minerals in due proportions, of about 18 per cent. Katamorphism

means a greater volume-increase, by perhaps 40 per cent., when pore-space is figured, on the basis of experimental determinations of pore-space of the different classes of sediments, again combined in the stated proportions. There is still greater increase of volume if the substances remaining in solution, such as salts in the ocean, be calculated as solids. On the other hand, if only the residual materials from weathering are taken into account, not the chemical sediments, it may be shown that in spite of the increase in volume of certain minerals, the mineral volume of each of the principal rocks developed from the residual weathering materials has decreased. Volume-changes will be discussed in more detail in another article.

In general, katamorphism means simplification, both chemical and mineralogical, sorting, segregation of like substances, increase of volume, hydration, carbonation and oxidation—three processes usually involving liberation of heat. There is a net liberation or running-down of energy. Katamorphism is a great concentrating operation, with its maximum effect on igneous rocks, but also acting on sedimentary rocks so far as these contain minerals not already katamorphosed.

Ores, whatever their ultimate origin, while insignificant in bulk as compared with the sediments, illustrate well the net results of repeated concentrations, physical and chemical, under katamorphism. Whether we start with the ores as original magmatic segregations, or with ores resulting from igneous "after-action," or with ores derived directly from the katamorphism of igneous or sedimentary rocks, the ores become concentrated and segregated, and to a certain extent simplified, by katamorphism, and the richness and value of the metallic ore deposits are in a broad way proportional to the extent to which they have been katamorphosed. While some of the magmatic segregations may have value without katamorphism, it is certain that their value is increased by katamorphism. When we consider the iron ores, the lead and zinc ores of the Mississippi Valley, and the oxidized and enriched sulphide zones of copper and other vein and replacement ores, the economic importance of katamorphism in the ore-depositing processes is obvious. A classification of ores in terms of metamorphism is a suitable one for instructional purposes, in that it emphasizes the correlation or identity of ore-depositing and

concentrating agencies with the common ones effecting the metamorphism of the lithosphere as a whole.

Stages in the partial redistribution of the elements above outlined appear in igneous rocks and in sedimentary rocks, so far as these have not become completely adapted to katamorphic conditions. Conglomerates, arkoses, and graywackes are largely in this class. Such partial changes are kaolinization, sericitization, and silicification of acid feldspars, or the alteration of basic feldspars by the development of epidote-zoisite, calcite, or prehnite and kaolin, or the change of augite to hornblende with separation of calcite, or of hornblende to chlorite and epidote with separation of quartz and iron oxide. In fact, most described "metamorphic" changes are of this partial kind, and the fact is frequently lost sight of that the completion of the observed alteration means ultimately the development of the simpler minerals of the sediments. It does not follow that the derivatives of the authigenic minerals of the igneous rocks are in each case less complex chemically than the original mineral. Epidote is as complex as feldspar, hornblende as augite. But the change is accompanied by the separation of other minerals that are less complex, such as kalin and calcite, and there is increase in volume when all end-products are taken into account, making the term "katamorphism" clearly applicable to the alteration. It may be emphasized that the long list of partial alterations of igneous rocks occurring in the upper part of the lithosphere are, with few exceptions, katamorphic in this sense, that they are usually accompanied by a separation of varying amounts of the end-products of alteration observed in sedimentary rocks. This phase of the subject will be discussed in another paper. With this clearly in mind, the study and understanding of the alterations of igneous rocks in upper zones become simplified.

In this connection, the question may be suggested: What are the broad differences between the metamorphism of surface volcanics and plutonic rocks, or between acid and basic rocks? It is not to be supposed that they alter equally in response to the demands of environment. Certain features of these differences are now known, but the subject has not yet been put on a systematic basis.

Cementation.—No sooner do the sediments, the end-products of

katamorphism, reach their maximum incoherency, when the reverse, or reascensional process, is initiated, and they begin to strengthen themselves. Their pore-space becomes lessened under their own weight or that of superior beds, and solutions drop their load in the interstices; the rock becomes cemented. The tendency toward cementation seems by observation to be at its maximum at or just below the level of ground-water. Van Hise defines the belt of cementation as extending from the ground-water level to the lower limit of free movement of water; i. e., to the bottom of the zone of fracture. Cementation consists essentially of a consolidation and selective addition of materials in response to environmental demands for greater coherency. The principal chemical change is due to loss of water and to the proportions of cementing materials added. The resulting rocks are shales, sandstones, quartzites, and limestones, with the same kinds of minerals as in the unconsolidated sediments. The source and nature of the cementing materials may be summarized roughly by comparing the materials available in solution from the weathering of igneous rocks with the requirements of the sediments in the proportions above assumed. Observed percentage losses of elements—alumina being assumed constant, when averaged for cases of so-called "complete" weathering—show frequently about a 33 per cent. total loss of substances in solution when alumina is figured as constant. A hundred pounds of average igneous rocks therefore would contribute to solutions 33 pounds of material, of which 23 pounds is silica, 8 pounds calcium and magnesium carbonates, and the remainder soda, potassa, iron oxides, etc. This material is delivered partly through the overground circulation ultimately to the ocean, and partly to the underground circulation, where it becomes available for cementation. After taking out enough of the materials in solution to afford the ocean salts and the chemical and organic sediments in their known proportion to the total, the overwhelming dominance of silica is apparent in the materials left for cementing purposes. Calculations show that of the net amount of 23 pounds of material available for cementation in our average case, fully 20 pounds are silica. This is not out of accord with observed abundance of cements, when we take into account the mass of silica used in cementing shales, usually not considered. It is possible that,

with liberal allowances for mechanical consolidation, the muds may still use more cementing material than other sediments combined.

Cementation also affects igneous rocks to the extent of filling fissures and other openings, but the process is insignificant in terms of the effect on the igneous rock itself, as compared with the effect on sediments.

Anamorphism.—When the cemented sedimentary rocks reach conditions of sufficient heat and differential pressure—which usually, though not always, means, when they reach the depth of rock-flowage—the reascensional, or constructive, development of the rocks continues under a set of processes which Van Hise has collectively designated as *anamorphic*. The minerals are recrystallized. Some of the simple mineralogical and chemical units become combined into relatively complex ones. The kaolin of shales becomes dehydrated, and this and other alumina silicates present are combined with the minor amounts of bases present to produce anhydrous silicates, which usually develop with a dimensional parallelism to meet the differential stress conditions, giving the rock a flow cleavage or schistosity. The quartz of the sandstones and quartzites combines with the minor amounts of clay and bases present to develop mica or other silicates—again usually, though not always, with parallel structure. The calcite of the limestone recrystallizes coarsely, usually without parallel structure, though sometimes possessing it; and there is a combination of the calcium with the small amounts of alumina silicates and bases which may be present, to develop pyroxenes, amphiboles, garnet, chloritoid, and other heavy anhydrous minerals. Chemically, the dominant processes are silication (and decarbonation) and dehydration, with a little deoxidation. The volume is reduced by closing pore-spaces, by the development of minerals with a higher average density (when taken in proportion of abundance), and, most important, by loss of materials. There is a tendency toward local mixing of substances, rather than segregation. Ores are modified, but not simplified and segregated. Adaptation to environment means, in short, the development of hard, dense crystalline slates, schists, and gneisses, some of the minerals of which approach more nearly in complexity those of the igneous rocks than do the minerals of the sediments.

Whether with more intense anamorphic conditions the sedimentary rocks actually pass into igneous rocks by subcrustal fusion or some analogous process, is yet a question which it is difficult to decide by direct observation, and which is partly a matter of definition. The burden of proof rests on those who hold that actual evidences of the change may be observed. It is easy to conceive that slightly assorted sediments containing essentially the minerals of the original igneous rocks may take on the characteristics of igneous rocks under these conditions; but, in proportion as the ultimate products of katamorphism have been developed and there is corresponding segregation of the simpler compounds, it is difficult to tell how these may again be brought together on any large scale to reproduce the proper mineralogical and chemical combinations of the igneous rocks. While silicates are developed, the main mass retains its simpler chemical characteristics and can be often distinguished from an igneous rock. If, as held by Van Hise, the processes of katamorphism and anamorphism both take place with a liberation or running-down of energy when both chemical and physical factors are considered, the completion of the metamorphic cycle on any broad scale seems doubtful.

It is further not clear whether the development of schists and gneisses from igneous rocks is predominantly katamorphic or anamorphic for the minerals of the igneous rock. In some observed cases the change is clearly katamorphic, such as the common development of hornblende from augite, of the alteration of a basic feldspar to a more acid feldspar with separation of clay and calcite, or the alteration of a potash feldspar to kaolin and sericite, although, as already indicated, one of the resulting minerals may be fully as complex as the original minerals. It is also equally certain that the observed development of heavy, anhydrous minerals, such as garnet, in the schistose igneous rocks means anamorphism.

The cycle.—The sequence of destructive and reconstructive changes above outlined constitutes a partial metamorphic cycle. If the slates, schists, or gneisses ever take on the characteristics of igneous rocks, through fusion and mixing, the cycle is complete. A necessary consequence of the cycle theory is that in the same zone changes may be both destructive and constructive—destructive to

igneous and crystalline rocks, constructive to sedimentary rocks made up of end-products of katamorphism. It is true that the katamorphism of an igneous rock is most rapid and effective at the surface, while the cementation of the sediments occurs best at and immediately below ground-water level, and anamorphism of sediments begins only when the zone of rock-flowage has been reached. Thus there is a vertical succession of metamorphic zones, each with its own distinguishing characteristics; but in each of these are

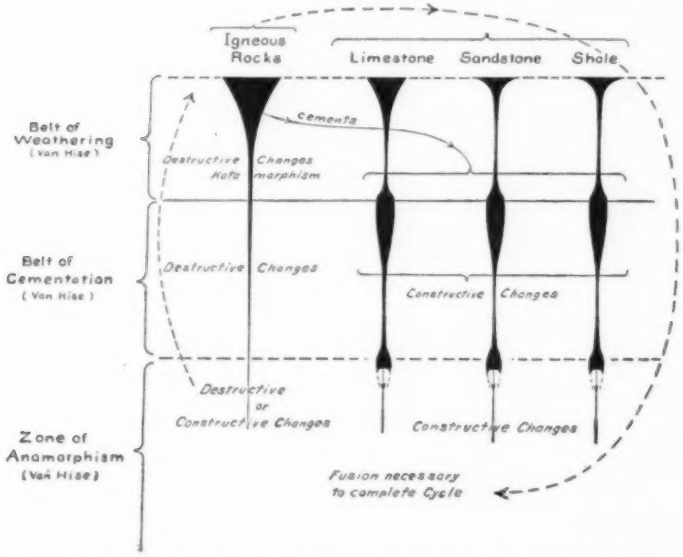

FIG. 2.—Sketch to show principal changes of principal rock in relation to zones of metamorphism. Thickened line indicates locus of maximum change. Horizontal lines indicating boundaries of zones are not corrected for thickness of zones or varying depth of zones for different rocks.

subordinate changes on opposite sides of the cycle. Katamorphism of an igneous rock near the surface is important, while, in the same zone, there is a minor amount of cementation of sedimentary rock. Cementation of sedimentary rock is important below ground-water level, where an igneous rock undergoes a relatively small amount of katamorphism. Anamorphism of certain sediments, especially

shales, may occur, while igneous rocks under the same conditions tend to katamorphism. In a highly idealized form the distribution of the changes with regard to zones, kinds of rocks, and kinds of changes, may be represented as in the figure on p. 312, in which the extent or importance of the change is represented in each case by thickness of line.

Van Hise states that the processes in each of the metamorphic zones may be reversed, thus in a way recognizing the cycle principle, but his full discussion emphasizes the dominant conditions and changes of the zones to such an extent that the student sometimes infers that all rocks in a given zone act alike. Grubenmann described three zones of schist-making—upper, middle, and lower—with the implication that all rocks suffer uniform changes in a given zone. Chamberlin and Salisbury imply the cycle idea in their use of the terms "descensional" and "reascensional" as applied to rock-changes, though the account of alterations and conditions is necessarily elementary. It is the purpose of the present paper to emphasize the necessity of the cycle theory in interpreting the zones of metamorphism. The "zonal" classification permits of necessary grouping of dominant phenomena, but confusion is likely to result unless the zones are considered in connection with particular rocks and alterations, and contrasting kinds of results for each zone are clearly discriminated.

Rôle of igneous rocks in metamorphic cycle.—The part taken in the metamorphic cycle by contact action of igneous rocks is most conspicuous in the anamorphic or constructive phases of the cycle, and may be regarded in general as furnishing higher temperature and pressure and hot solutions for the acceleration of anamorphism and for developing anamorphism in higher zones where the conditions are otherwise not anamorphic. Along the contacts are developed dense, complex, anhydrous silicates, such as garnet, staurolite, andalusite, amphibole, pyroxene, etc., and the rocks are recrystallized. Yet it is also true, especially near the surface, that the advent of igneous rocks brings about katamorphism in the adjacent rocks through the agencies of the hot waters and gases, magmatic, meteoric, or both, accompanying and following their introduction. In this class probably belong in part the prophylitic and allied alterations adjacent to

ore-bearing veins in igneous rocks. The quantitative classification of igneous contact effects in terms of katamorphism and anamorphism has not yet been accomplished, or for that matter more than begun on any systematic scale. It is likely to yield interesting results. But whatever the specific relations of the influences of igneous rocks with conditions determined by depth they should require little essential revision of our conception of the metamorphic cycle for the reason that the cycle is based on a comparison of net results, and not on a comparison or weighting of the specific causes which have contributed to these results.

Classification of rocks.—The term "metamorphism" has in the past been largely applied to the development of slates, schists, and gneisses. This use of the term is implied in the prevalent textbook classification of rocks into igneous, sedimentary, and metamorphic divisions. The student comes to realize only with difficulty the fact that sedimentary rocks result from alteration of igneous rocks, just as do the so-called metamorphic rocks. Van Hise and others have included all rock alterations under metamorphism, and the same practice is observable in the descriptions of rock alterations by certain petrographers when they include under metamorphism many mineral changes which ultimately develop the sedimentary minerals. The development of the cycle idea further emphasizes the necessity of the broad use of the term "metamorphism," and the desirability of Van Hise's terms, "anamorphism" and "rock-flowage," to cover the schist-making changes formerly alone considered under metamorphism. With terms thus defined, the primary genetic classification of rocks becomes a dual one, *igneous* and *metamorphic*, the latter class being dually subdivided into the contrasting *sedimentary* and *schist-slate-gneiss* groups.

NOTES ON THE PALEOZOIC FAUNAS AND STRATIGRAPHY OF SOUTHEASTERN ALASKA[1]

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INTRODUCTION

The localities referred to in this paper are located on the islands of the Alexander Archipelago and along the shores of the narrow coastwise strip west of British Columbia sometimes called the Panhandle of Alaska.

During the summer of 1905 the writer, in company with Mr. C. W. Wright, made a boat journey of about 600 miles along the coasts to the southeast of Glacier Bay and the Lynn Canal. Collections were made from nearly all of the localities at which fossils had previously been found in this region by Mr. Wright and others, and from a number of new ones.

The trip was undertaken primarily for the purpose of aiding in the work of correlating and mapping the rocks of southeastern Alaska, upon which Messrs. F. E. and C. W. Wright have for some time been engaged. Alaskan faunas have a wide general interest to paleontologists, owing to their intermediate position between the faunal provinces of America and Asia. So little has been published on the faunas of this important region that a preliminary statement of the results thus far obtained seems justified in advance of the comprehensive work of the Wrights. A brief statement of the stratigraphic succession is essential to the comprehension of the summary of the faunas. In presenting this outline of the stratigraphic succession the writer wishes to acknowledge his indebtedness to previous workers in this region, and particularly to the Wrights, upon whose work it is in part based. More explicit reference to the previous work in the region is offered in the following brief discussion of the more important contributions relating to this field.

[1] Published by permission of the Director of the U. S. Geological Survey.

LITERATURE

Casual observations on the Paleozoic rocks of southeastern Alaska appear in the writings of some of the travelers who visited the region during Russian occupation. The most important of the early papers is one by Dr. Grewink, a Russian, who, although he never visited Alaska, published a paper in 1850[1] which contains many geographical and some geological data concerning southeastern Alaska. This work is based largely on collections and data obtained by a Russian naval officer. The finding of a loose specimen of the Silurian fossil *Catenipora escharoides* near Sitka is reported by Grewink.[2]

In 1855 Isbister published a summary of then existing knowledge of the geology of northwestern America, with a geological map which included Russian America.[3] The data relating to southeastern Alaska[4] are drawn from Grewink and the "Geological Appendix" to Captain Beecher's *Voyage to Behring Straits*. The crude inaccuracy of the map made it of little or no value as a basis for actual work in the region.

In 1863 Mr. W. P. Blake made a reconnaissance of the Stikine River and published some notes on the rocks observed.[5] In 1868 Mr. T. A. Blake published a paper[6] on southeastern Alaska which contains observations on the lithologic characters of the rocks near Sitka and along Chatham Strait.

The pioneer work of George W. Dawson on the Chilkoot Pass and Stikine River[7] sections in 1888, and of C. W. Hayes along the Taku Inlet and River in 1891,[8] was the first important contribution

[1] "Beitrag zur Kenntniss der orographischen und geognostischen Beschaffenheit der Nord-West-Küste Amerikas mit den anliegenden Inseln," *Verhandlungen der Russischen kaiserlichen mineralogischen Gesellschaft zu St. Petersburg*, 1848, 1849 (1850), pp. 76—432.

[2] *Ibid.*, p. 93.

[3] *Quarterly Journal of the Geological Society of London*, Vol. XI (1855), pp. 497–520, map.

[4] *Ibid.*, pp. 518, 519.

[5] *Petermans Mitteilungen*, Vol. X (1864), pp. 171–75. 4°.

[6] *American Journal of Science*, Second Series, Vol. XLV (1868), pp. 242–47.

[7] *Annual Report of the Geological Survey of Canada*, N. S., Vol. III, Part 1, pp. 53*b*–59*b*, 176*b*.

[8] *National Geographical Magazine*, Vol. IV (1892), pp. 117–59.

to our knowledge of the stratigraphy of southeastern Alaska. These three traversers of the coastwise belt established the fact that the sedimentaries are cut by a granite belt of great width and length.

In 1892 Mr. H. P. Cushing, a member of Professor Reed's party, published a paper on the bed-rock geology about Glacier Bay, which includes a report on a small collection of fossils from a limestone having "a thickness of several thousand feet." These were determined by Professor H. S. Williams as Paleozoic.[1] Later this collection, with the addition of a coral which appears to have been obtained from a glacial moraine, was reported to be Carboniferous on the authority of Professor Williams.[2] Professor J. J. Stevenson, who obtained the coral considered it and the Leperditias to indicate a horizon "not younger than Middle Devonian."[3]

Professor H. F. Reid in 1895 published a report on "Glacier Bay and Its Glaciers,"[4] in which he quotes this determination by Williams of the Carboniferous age of the Glacier Bay limestones. On the basis of this determination Reid suggests the correlation of the Glacier Bay "Carboniferous" and some of the argillites and limestones described by Hayes in the Taku section, 100 miles to the eastward, with the Glacier Bay limestones. The Cambro-Silurian age of the argillites underlying the limestone at Glacier Bay is suggested by Reid because of a supposed analogy of his section to one of Dawson's some 300 miles to the southeast, in which Carboniferous faunas are said to follow a Cambro-Silurian horizon. The Cushman fossils were later examined by Schuchert, who reported them to be Silurian, with the exception of the coral from the moraine, concerning which Schuchert agreed with Stevenson in reporting it to be an *Acervularia*, representing a Devonian horizon.[5] Fossils recently collected by the Wrights leave no question as to the Silurian age of the Glacier Bay limestones.

In 1895 Messrs. Dall and Becker visited southeastern Alaska in order to study its gold and coal resources. The observations on the

[1] *National Geographical Magazine*, Vol. IV (1892), p. 59.

[2] *Sixteenth Annual Report*, U. S. Geological Survey, Part 1, p. 434.

[3] *Scottish Geographical Magazine*, Vol. IX (1893), p. 70 (separate p. 5).

[4] *Sixteenth Annual Report*, U. S. Geological Survey, Part 1, pp. 433, 434.

[5] Brooks, *Professional Papers No. 1*, U. S. Geological Survey, p. 20.

stratigraphy in Mr. Becker's paper[1] relate to the rocks in the vicinity of the gold mines. No correlations with rocks elsewhere are attempted.

Dall's paper, which relates solely to post-Paleozoic rocks, has attached as an appendix a paper by Charles Schuchert.[2] This paper gives a list, with notes, of fossils obtained at Kuiu Island by Messrs. Dall, Becker, and Brightman. Professor Schuchert referred these fossils to two horizons, the Devonian and Carboniferous. It will be shown elsewhere in this paper that all of these fossils are of Upper Carboniferous age.

In 1901, Mr. Alfred H. Brooks,[3] incidental to a study of the mineral deposits of the Ketchikan district, collected considerable data on areal and structural geology. He also carried a hasty reconnaissance northward as far as Skagway, and thence westward to Sitka. In his report he brought together, not only his own data, but also those of previous investigators, and included a geologic sketch map of southeastern Alaska and a provisional table of correlations.

Mr. Arthur C. Spencer[4] in 1903 made a study of the geology and mineral resources of a strip of the mainland extending southward from Berners Bay to Snettisham, while in the same year Mr. C. W. Wright[5] carried a reconnaissance northward to the international boundary in the Porcupine district, in which he has shown the presence of a Carboniferous limestone. Since then Messrs. F. E. and C. W. Wright have extended their work so as to cover nearly the entire province, but only their preliminary statements have been issued. Accompanying one of these is a preliminary geological map[6] covering most of the area.

Professor B. K. Emerson, one of the geologists of the Harriman expedition, has published some notes on the lithology and correlation of the rocks at points where their steamer touched.[7] Most of these

[1] *Eighteenth Annual Report*, U. S. Geological Survey, Part 3 (1898), pp. 7–86, 96, 97.

[2] "Report on Paleozoic Fossils from Alaska," *Seventeenth Annual Report*, U. S. Geological Survey, Part II, pp. 898–906.

[3] *Professional Paper No. 1*, U. S. Geological Survey, pp. 1–119; *Bulletin of the Geological Society of America*, Vol. XIII (1901 [1902]), pp. 253–66.

[4] *Bulletin No. 287*, U. S. Geological Survey, 1904 (1907).

[5] *Bulletin No. 236*, U. S. Geological Survey, 1904.

[6] *Bulletin No. 284*, U. S. Geological Survey, 1906, pp. 30–54, Plate II.

[7] *Ibid.*, p. 20.

relate to Mesozoic terranes. In his observations on Glacier Bay Professor Emerson revives an old error by referring the limestones of that locality to the Carboniferous,[1] unaware, apparently, that they had been shown to be of Silurian age.[2]

Quite recently Brooks has briefly summarized the more essential facts concerning the stratigraphic succession in southeastern Alaska.[3] A small-scale geologic map of the whole of Alaska, so far as covered by surveys, accompanies this report. In this paper appears the first notice of the presence of Silurian horizons at Freshwater Bay and Kuiu Island.

GENERAL GEOLOGIC RELATIONS

Southeastern Alaska is a region in which a wide range of geologic agencies have operated to produce a complex and intricate stratigraphic record. Volcanic and igneous rocks, either as surface flows or as intrusions, have been developed in this area at frequent intervals

[1] *Harriman Alaska Expedition*, Vol. IV (1904), pp. 16–23.

[2] A. H. Brooks, *Professional Paper No. 1*, U. S. Geological Survey, 1902, pp. 19–21.

[3] "The Geography and Geology of Alaska," *Professional Paper No. 45*, U. S. Geological Survey, 1906, pp. 208, 210, 211, 219, 221, 222.

from the Paleozoic down to the present. The sedimentary beds are known to include Tertiary, Mesozoic, and Paleozoic horizons as far back as the Silurian. By far the greater part of the sedimentaries belong to the Paleozoic, but a considerable thickness of the Mesozoic has been found in a few sections. The Mesozoic and Paleozoic beds have been folded together in a series of flexures, generally of the open fold type after which the Tertiary, now found only in a few isolated basins, was deposited upon them. The general direction of the strike of the beds is northwesterly and southeasterly, approximately parallel to the coast-line. The inclined beds have been cut by extensive intrusions. These take courses parallel in a general way to the strike of the sedimentaries. The granites, which comprise the bulk of the Coast Range mountains, are the most important of these intrusive masses. This granite belt has a width of 40 to 80 miles, and extends the entire length of the coast strip and beyond it both north and south. Granite intrusions, which are usually more or less local in character, occur through the islands. The older rocks over considerable areas in some parts of the region are buried under lavas of Tertiary age.

The shales and limestone of the sedimentary series have in many parts of the region been altered to marbles and schistose rocks by the intrusives and deformational agencies. Frequently the alteration has been sufficient to destroy all traces of organic remains.

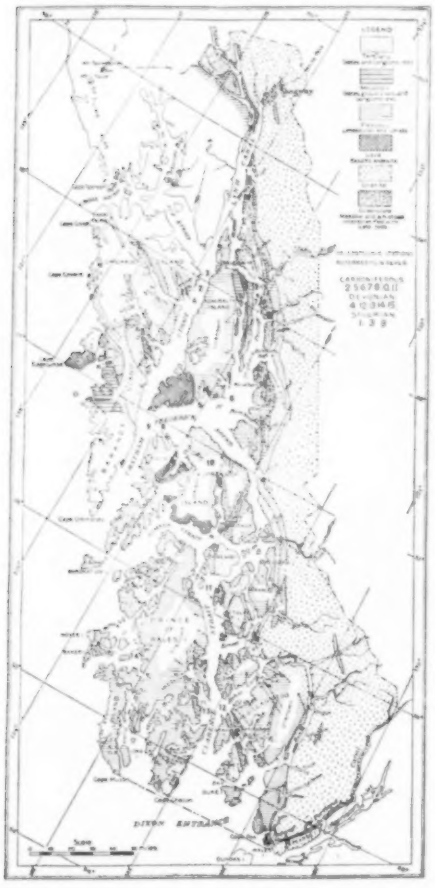
The general order of the stratigraphic succession is shown in the following table:

PROVISIONAL TABULAR STATEMENT OF STRATIGRAPHY

Age		Lithological Character	Correlation with Nomenclature of Brooks*	Thickness Feet
Carboniferous	Upper Carboniferous	Light-colored limestone	Ketchikan series	600±
	Middle Carboniferous	Argillites, cherts, shales, sandstone, and greenstone		?
	Lower Carboniferous	Dark-gray limestones and interbedded cherts		1500±
Devonian	Upper Devonian	Dark-red volcanic material, limestone and greenstone		?
	Middle Devonian	Gray limestone	Vallenar series	200±
	Lower Devonian	Gray limestone		200±
Silurian		Gray and buff limestones	Wales series	3000±
Silurian or pre-Silurian		Graywacke, cherts, and some dark limestone		?

* *Professional Paper No. 1*, U. S. Geological Survey, 1902, pp. 41–45.

The limits of the three subdivisions or series of the Paleozoic proposed by Brooks, which are shown in the preceding table, correspond to those of the Carboniferous, Devonian, and Silurian rocks of the region, so far as they were recognized at that time.



Our present knowledge of the section is too incomplete to make any definite statements concerning the contact relations of the several divisions of the column. While it is probable that unconformities exist within the Paleozoic, evidence of them has not been observed by the writer.

Brooks observed what he considered evidence of unconformity at the base of the Devonian at Long Island (13)[1] and Vallenar Bay (12).[1] It may be stated, however, that at neither of these localities is the age of the "older beds" known. The evidence of unconformity consequently rests on the character of the contact between the Devonian and the older beds. This relationship, as observed by the writer at Long Island, appears to be open to another possible interpretation than that of unconformity. On the north side of Long Island the

[1] Numbers refer to collecting stations on map. *Professional Paper No. 1*, U. S. Geological Survey, 1902, p. 21.

relative position of the limestone and inferior beds may be the result of a fault which has lifted the basal igneous beds considerably higher than the limestone at one or more points. On the south shore the strike and dip of the limestones and the underlying igneous beds, which probably represent submarine volcanic flows, were in harmony where observed. In referring to this supposed unconformity the writer wishes not to deny its existence, but to point out that further evidence is required to demonstrate it.

The preliminary geological map by Messrs. F. E. and C. W. Wright is here reproduced[1] in order to show the location of the points from which the fossils on which this paper is based were obtained. The several collecting stations are indicated by numbers, and the horizon of each is shown by a geological grouping of the numbers at the margin of the map.

SILURIAN

The oldest fauna which has been found in the region is of Silurian age. A great thickness of rocks, mostly argillites, underlies the limestones holding Silurian fossils. These lower beds, in which no fossils have been found, have an aggregate thickness of several thousand feet, as exposed on the west coast of Kuiu Island. The great thickness of these beds and their position below limestones known to be of Silurian age strongly suggest their pre-Silurian age, although no paleontologic evidence of this has been obtained.

Two horizons of the Silurian have been recognized. The older of these is represented by a small fauna which has been found on the northwest coast of Kuiu Island (10).[2] In the limestones northeast of Mead Point the following fauna occurs:

Diphyphyllum ? sp.
Conchidium knighti (Sow.)
Whitfieldella sp.
Holopea cf. servus Barr.
Murchisonia sp.

None of the species are abundant, with the exception of *C. knighti*, which is represented by great numbers of large shells in one thin bed of limestone.

C. knighti is one of the characteristic fossils of the Aymestry limestone of the Ludlow group of England. It is known also from

[1] Republished from *Bulletin No. 284*, U. S. Geological Survey, 1906.

[2] Locality numbers refer to the map.

Russia and Bohemia. There appear to be no authentic records of its occurrence in the Silurian faunas of the United States. The nearest equivalent of this fauna in eastern America is the Niagara fauna. While none of the species collected are identical with Niagara species, *Conchidium knighti* is very closely related to *C. nysius* of the Niagaran fauna.

The Kuiu island fauna occurs in the midst of a limestone series which appears to be 2,000 feet or more in thickness. Other portions of the series which were examined appeared to be barren. Upward

FIG. 1.—Silurian beds at Freshwater Bay.

these limestones seem to terminate with volcanic breccias, while below they pass into cherts and argillites of undetermined age.

The later Silurian horizon does not appear to be present in the Kuiu Island section. It occurs at Freshwater Bay (4), where more than a thousand feet of gray limestones, which precede the beds carrying Devonian fossils, outcrop along the south side of Freshwater Bay. The appearance of the lower portion of this series is shown in the accompanying photograph (Fig. 1). The lower two-thirds of this series comprises dark-gray, thinly laminated limestones. *Leperditias* of an undetermined species occur abundantly in certain beds in the lower part of the series. A few fragments of another and larger crustacean, probably a *Ceratiacaris*, are associated with them.

These crustaceans comprise the fauna of the lower 700 feet of the section, so far as discovered.

In the upper 300 feet of the limestones of the section a crustacean fauna also predominates, but the types represented are unlike those of the preceding division. One of the conspicuous forms in this fauna is a large undescribed ostracod provisionally referred to *Isochilina* by E. O. Ulrich, having a length of 1¼ inches. Fragmentary specimens indicate the presence of one or more other species of large ostracods, which together with a new species of *Ceratiacaris* are associated with the large *Isochilina*. Other forms occurring in this portion of the section are *Zaphrentis?* sp., represented by a single specimen, *Meristella tumida* Dalm.? and *Megalomus* sp. undt. The *Megalomus* is a large and very thick-shelled bivalve comparable in this respect with *Megalomus canadensis* of the Guelph, and identical with a species occurring in the limestone at Glacier Bay.

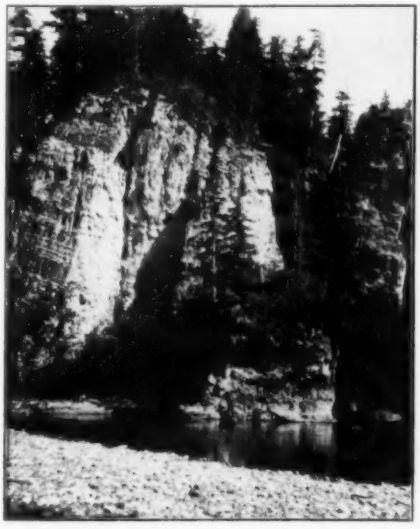


FIG. 2.—Upper Carboniferous limestone, Hamilton Bay, Kupreanof Island.

While none of the forms occurring in the two lowest divisions of this section have been identified with known species, the dominance of the large ostracods and the massive-shelled *Megalomus* and thick-shelled *Murchisonias* point to a late Silurian age of the fauna. The horizon represented is apparently about that of the Guelph.

The Silurian fauna of Freshwater Bay is found also at Glacier Bay, to the northwest. A small collection in the National Museum made by Cushman, and a much larger collection by Mr. F. E. Wright,

show the faunas of the two localities to bear the closest resemblance.

The horizon represented by the fauna at Freshwater and Glacier Bays is not known as yet elsewhere in Alaska. The Kuiu Island Silurian fauna differs very materially in its facies from other known Silurian faunas of Alaska, but the same horizon appears to be represented by the Silurian found by the writer on the Porcupine River, in northeastern Alaska, during the last summer.

FIG. 3.—Lower Devonian limestone (*B*) and basal igneous beds (*A*) at Long Island.

DEVONIAN

No complete section of the Devonian is known in southeastern Alaska. The collections from various points taken together, however, show the presence of Upper, Middle, and Lower Devonian horizons. The earliest fauna of the Devonian which has been found occurs in the section at Long Island, Kasaan Bay (13). The bedrock of the shores of the bay is composed chiefly of the Kasaan greenstones and cherts. The limestone of Long Island and its associated igneous rock is supposed to be interpolated in the greenstone series. The surface rocks of the island comprise a limestone series resting on

a bedded igneous rock, with which the limestones appear to be conformable. Both series are shown in Fig. 3. An estimate of the thickness of the beds along the south shore of the island gives the following section exposed between the east end of the island and the inlet to the Salt Pond:

	Feet
c. Hard, dark-gray limestone, slightly darker than *b*	270
b. Hard, blue, fine-grained limestone, fracturing easily in any direction .	200
a. Stratified buff or cream-colored siliceous beds of igneous origin . . .	90
	560

FIG. 4.—Middle Devonian limestone, Long Island.

The two divisions of the limestone series are conformable with each other, and the upper and lower portions are very similar in lithologic characters. Fig. 4 shows the lower beds of division *c*. The faunas of the two divisions of the limestone, however, show marked differences. The fauna of the upper portion of the limestone series was first discovered by Brooks, who collected some fossils from it which Schuchert determined as Middle Devonian.[1] The lower fauna appears not to have been represented in the collection studied by Schuchert. The character of the fauna in the lower portion of the limestone series is indicated by the following list:

[1] *Professional Paper No. 1*, U. S. Geological Survey, p. 43.

Stictopora sp.
Cladopora sp.
Delthyris sulcatus Hisinger.
Sanguinolites sp.
Cardiola sp.
Hercynella nobilis Barr.
Hercynella bohemica Barr.
Holopea sp.
Murchisonia angulata Phillips.
Murchisonia sp. 1
Murchisonia sp. 2
Planitrochus sp.
Planitrochus near amicus(Barr.)Perner.
Loxonema sp.
Holopella sp.
Trochonema sp.
Euomphalopteris ? sp.
Beyrichia ? sp.
Leperditia sp.
Orthoceras sp.
Orthoceras near anguliferas de Arch. and de Vern.

The occurrence of the genus *Hercynella* in this fauna is of considerable interest, since it has not been found heretofore in America. *H. bohemica* occurs in the lower Devonian of the Ural Mountains. Both *H. bohemica* and *H. nobilis* are present in Étage F of Barrande's Bohemian section. Their presence in the fauna at Long Island indicates that the latter is much more closely related to the European and Asiatic than to the American faunas outside of Alaska. This lower fauna at Long Island represents the lowest Devonian horizon which has been found in southeastern Alaska.

In the upper portion of the higher limestone, *c*, the following fauna is found:

Favosites radiciformis Rom.
Cyathophyllum sp.
Orthophyllum ? sp.
Zaphrentis sp.
Calceola cf. sandalina Lam.
Syringopora sp.
Lingula sp.
Atrypa spinosa Hall.
Atrypa reticularis (Linn.)
Atrypa hystrix Hall.
Gypidula optatus (Barr.)
Gypidula cf. intervenicus (Barr.)
Meristella cf. barrisi Barr.
Stropheodonta stephani (Barr.)
Stropheodonta comitans Barr.
Spirifer sp.
Spirifer hians Bich.?
Spirifer thetidis Barr.
Spirifer subcomprimatus Tsch.
Spirifer sp.
Spirifer indeferens Barr.
Spirifer sp.
Reticularia ? sp.
Rhynchonella cf. amalthea Barr.
Rhynchonella livonica Buch.
Pugnax sp.
Dalmanella occlusa Barr.
Schizophora macfarlani Meek.?
Schizophora striatula Schloth.
Streptorhynchus sp.
Camarotochia ? sp.
Cypricardinia ? sp.
Conocardium cf. bohemicum Barr.
Conocardium sp.
Lucinia cf. proavia Goldf.
Leptodesma sp.
Mytilarca ? sp.
Nuculites sp.

Telinopsis sp.
Holopella ? sp.
Loxonema ? sp.
Murchisonia sp. 2.
Murchisonia sp. 1.
Naticopsis sp.
Oriostoma sp.
Oriostoma princeps var. Oehlert.
Euomphalus cf. planorbis d'Arch. and Vern.
Tremanotus cf. fortis Barr.
Tentaculites sp.
Ooceras sp.
Gomphoceras ? sp.
Orthoceras sp.
Cytherella ? sp.
Entomis pelagica Barr.
Lepterditia sp.
Cyphaspis sp.
Proetus sp.
Proetus cf. romanooski Tsch.

In place of the gasteropods, which are the dominant forms in the lower horizon, brachiopods are the predominant group in this upper fauna. The *Hercynellas*, which are abundant at one horizon in the lower beds, appear to be entirely absent. The upper fauna, however, agrees with the lower in its foreign affiliations. In it occur the peculiar coral *Calcoela*, common in the Middle Devonian of Europe, but not recorded from the American Devonian. Several species among the brachiopods are either identical with, or have their nearest analogues in European species.

The lower 40 feet of division *c* of the Long Island section furnished a fauna differing but slightly from that of the upper part. The following list indicates its character:

Cladopora ?
Cyathophyllum sp.
Camarotoechia sp.
Meristella cf. ceras Barr.
Spirifer sp.
Spirifer cf. thetides Barr.
Spirifer cf. cheiropteryx
Stropheodonta comitans Barr.
Orthonota sp.
Schizodus sp.
Conocardium cf. bohemicum Barr.
Euomphalus planorbis d'Arch and Vern.
Oriostome princeps var. Oehlert.
Tentaculites
Cyrtoceras sp.
Orthoceras sp.
Proetus cf. romanooski Tsch.

Both faunules of this upper limestone (*c*) are regarded as representing a Middle Devonian horizon.

There are no Devonian faunas in the United States with which the Long Island faunas can be compared. Their affinities seem to be all with the European faunas.

The Middle Devonian is represented also by a fauna occurring at Freshwater Bay (4), in the northeastern part of Chichagof Island.

On the south side of the bay the Silurian series previously described in this paper is terminated by 50 feet or more of Devonian limestones. These are dark steel-gray in color, somewhat arenaceous, and lie in strata 1 to 4 feet thick. These higher beds, which are largely covered at high tide, furnished the following species:

Orbiculoidea sp.
Chonetes cf. verneuile Barr.
Camarotoechia cf. billingsi Hall.
Leptostrophia n. sp.
Stropheodonta sp.
Stropheodonta stephani Barr.
Stropheodonta cf. fugax (Barr).
Pentamarella ? sp.
Reticularia ? sp.
Schizophoria sp.
Atrypa reticularis
Cypricardinia ? sp.
Cypricardinia contexta Barr.
Goniophora sp.
Pterinea sp.
Pterinopecten sp.
Schizodus sp.
Goniatites sp.
Orthoceras sp. 1.
Orthoceras sp. 2
Bellerophon sp.
Naticopsis sp.
Oriostoma sp.
Leperditia sp.
Dalmanites sp.
Proetus romanooski (Tsch.)

This fauna has but little resemblance to any of the Devonian faunas of eastern America. Its nearest faunal equivalents are to be found in the Devonian of central Europe and Russia. Two of the species occur in Étage F of Barrande's Bohemian section. One of the trilobites which occur abundantly in this fauna appears to be identical with species described by Tschernyschew from the Ural Mountains as *Dechenella romanooski*. The presence of such forms as *Goniophora* sp., *Goniatites* sp., and *Proetus romanooski*, together with the general aspect of the fauna, points very clearly to its Middle Devonian age.

In the Freshwater Bay section igneous beds appear to occupy the entire upper Devonian interval. At Klawack (14), on the west coast of Prince of Wales Island, however, Mr. C. W. Wright made a small collection of fossils which show the presence of an Upper Devonian fauna in the southern part of the southeast Alaskan district. It contains *Zaphrentis* sp., *Productella hallana* Walcott, and *Spirifer anossofi* Vern. The two latter are represented by a number of specimens, and seem to be the most abundant fossils at the locality. *Sp. anossofi* is representative of the Ural Mountains fauna, but is closely related to *Spirifer hungerfordi* of the Iowa Devonian. *P. hallana*

is a common species in the western American Devonian, and is also found in the Ural Mountains. At another locality C. W. Wright has found *Spirifer disjunctus*. The discovery of these fossils distinctly proves the presence of the Upper Devonian fauna in southeastern Alaska. In many of the sections, however, the fauna will probably be found to be absent, owing to the prevalence of submarine volcanic flows during the Upper Devonian interval.

The Devonian section of southeastern Alaska resembles that of the Upper Yukon in respect to the important rôle played by igneous rocks in each. So far as the two sections are known, however, the sedimentary members present no strong points of similarity, except that the lowest member of each is a limestone formation. The faunas of the two regions are entirely unlike each other. The Mackenzie River section, which is the nearest Canadian Devonian section of which we have any very definite knowledge,[1] appears to have no strong points of resemblance, either lithologic or faunal, to the southeastern Alaskan section.

A few other localities besides those mentioned have furnished small collections of Devonian fossils. The small number of well-known species, or the poor state of preservation of the material from these localities, makes it undesirable to offer an opinion as to the horizons represented without considerable reservation. In one of these lots, which was collected from limestone beds on the south side of Kosciusko Peninsula, are crinoid stems, *Spirorbis* sp., *Atrypa* sp., *Cyrtina* cf. *billingsi* Meek, *Meristella* cf. *barrisi* Hall, *Cranaena* cf. *romingeri* Hall, *Orthis* cf. *arcuata* Phillips, *Pleurotomaria* sp.

Devonian fossils have been reported also from Kuiu Island by Professor Charles Schuchert.[2] In describing a collection obtained by Dall and Becker from Saginaw Bay, Kuiu Island (8), he states that they "unmistakably indicate the presence there of Carboniferous and Devonian strata."[3] A careful examination of the locality from which Schuchert's fossils came failed to discover any Devonian horizon. Recently the fossils which were considered Devonian by

[1] Canadian Geological Survey, *Contributions to Paleontology*, Vol. I, Part 3 (1891), p. 250; *Transactions of the Chicago Academy of Science*, Vol. I (1867–69), pp. 61–114, pls. 11–15.

[2] *Professional Paper No. 1*, U. S. Geological Survey, 1902, p. 43.

[3] *Seventeenth Annual Report*, U. S. Geological Survey, Part 1, p. 902.

Schuchert have been re-examined by Dr. Girty and the writer. They comprise specimens representing five or six species, most of which are common in the Upper Carboniferous fauna of Alaska. The specimens referred to *Conchidium* by Schuchert belong to the genus *Camarophoria* and are near, if not identical with, *C. margaritova*. This is a common and characteristic species of the Upper Carboniferous limestone in Alaska, not being known below it. *Spirifer* sp. undet. I is identical with a *Spirifer* collected from Carboniferous beds of Saginaw Bay by the writer, which Girty considers closely allied to *Sp. alatus* Schl. *Spirifer* sp. undet. II of Schuchert is represented only by a portion of the ventral valve, which is considerably worn. It shows traces of fine plications alternating with the seven or eight very coarse plications marking the surface. The one in the sinus is quite distinct. These minor plications distinguish it quite sharply from *S. arrecta*, with which it was compared, as well as from other Devonian brachiopods with which the writer is acquainted. The *Chaetetes* sp. undet. is probably a *Stenopora*. These supposed Devonian fossils all belong unquestionably to the Upper Carboniferous.

CARBONIFEROUS

The oldest Carboniferous fauna which has been found in southeastern Alaska was obtained at Freshwater Bay, in the northeastern part of Chichagof Island. This fauna was submitted to Dr. George H. Girty, who states, in a report furnished the writer, that, "while not unlike the American Lower Carboniferous or Mississippian, it resembles, and probably should be correlated with, the Russian Lower Carboniferous or *Productus giganteus* zone, or Mountain limestone." Freshwater Bay is the only locality visited where the Lower Carboniferous fauna has been found in southeastern Alaska. This locality is important also because the stratigraphic relation of the Lower Carboniferous to the older rocks may be observed.

On the northeastern side of the bay, and opposite the Silurian and Devonian limestones already described, the Carboniferous limestones form a low, narrow peninsula, never more than a few hundred yards in width, projecting out 4 miles from the mainland. The strike varies from N. 35° E. to N. 40° W., but generally has a northwesterly

and southeasterly trend. The dip is high, frequently 90°. It is sometimes easterly, and sometimes westerly, the direction of dip depending on whether or not the limb of the large fold to which all this peninsula and the older beds on the south side of the bay belong is slightly overturned at any given point. The thickness of the several divisions of the limestones which are exposed along the north shore of this peninsula is indicated approximately in the following section, which begins about one-half mile above (northwest of) North Passage Point (2):

	Feet
e. Breccia of large gray limestone fragments	100
d. Hard gray limestone, much fractured by numerous irregular joints, and breaking into small irregular fragments on weathering. Large *Productoids* common. Dip 30° to 90° toward southwest; strike N. 40° W.	90
c. Gray limestone with frequent bands of black chert. Fossils scarce. Strike N. 10° to 20° W. Dip 80° to 90° N. E.	275
b. Dark gray limestone with black chert bands. Fossils abundant near upper and lower limits. Average strike N. 30° E. Dip 70° to 80° N. W.	250
a. Limestone similar to *b*. Corals common	275
	990

Exposures on the north side of the bay and just west of the peninsula, which are lower but not continuous with this section, would add, if included in it, several hundred feet to its thickness. The total thickness of the Lower Carboniferous section is probably not less than 1,500 feet.

The following list, furnished by Dr. Girty, includes the more common species in the Lower Carboniferous beds at Freshwater Bay:

Zaphrentis sp.
Crinoid fragments
Diphyphyllum sp.
Productus giganteus Martin
Productus punctatus Martin ?
Productus aff. P. inflatus McChes.
Spirifer aff. S. trigonalis Martin
Cleiothyris aff. suborbiculoides McChes.

The Lower Carboniferous in southeast Alaska, while representing a different facies from that of the Mississippi Valley, is still much more closely allied to the Interior continental faunas than is the Upper Carboniferous fauna of this region. The Lower Carboniferous fauna is widely distributed in Alaska. If has been recognized as far north

as Cape Lisburne, on the Arctic coast,[1] and it occurs at numerous points on the Yukon and Porcupine Rivers in eastern Alaska.

Concerning the interval between the Upper and Lower Carboniferous faunas in this region we have but few data. No fauna representing it has been found.

The younger of the two Carboniferous faunas of southeastern Alaska is well represented in the limestones about Pybus Bay, on the southeast side of Admiralty Island (7), where they outcrop extensively along both arms of the bay. The limestones characterized by this Upper Carboniferous fauna have a thickness of about 600 feet at Pybus Bay. These Upper Carboniferous limestones are generally heavy-bedded or massive, as shown in the photograph (Fig. 2). The Lower Carboniferous limestones where observed have thinner bedding and are darker-colored than those of the higher horizon.

The following section, taken along the west shore of the east arm of the bay, indicates the character of the Carboniferous limestone (*c* of the section), and the associated beds:

		Feet
g.	Black to dark-gray argillaceous slates	300
f.	Covered interval	100
e.	Massive or heavy-bedded, gray limestone, with conchoidal fracture	40
d.	Light-gray limestone full of small, angular, cherty masses	80
c.	Light-gray cherty limestone in 10″ to 30″ bands, fossils abundant	600
b.	Red chert in 6″ to 20″ bands	300
a.	Black chert in 4″ to 10″ bands, with rarely a brown or red band	550
		1,970

The Mesozoic beds are represented by the two divisions *e* and *g* of the section. Whether the shales and the Mesozoic limestone are conformable or not, the section does not show, but the latter and the Carboniferous limestone are unconformable. The total thickness of the black slates cannot be determined from the outcrops which continue beyond the end of this section, since they belong to a series of low folds which do not bring the entire thickness of the beds to view. Other outcrops, however, just outside the bay indicate a total thickness of not less than 900 feet for these black slates, which have been referred provisionally to the Lower Cretaceous by Dr. Stanton, on account of the occurrence in them of a Cretaceous type of *Aucella*.

[1] *Bulletin No. 278*, U. S. Geological Survey, pp. 22–25.

The fauna of the Pybus Bay limestone is the same which has been previously referred to the Permian in Alaska. Dr. George H. Girty, to whom the writer is indebted for the determination of the horizons represented by the Carboniferous collections, states, however, that he finds

> that a greater resemblance exists with the Gschelian stage of the Russian section than with the Russian Permian. Provisionally, therefore, I will correlate this horizon with the Gschel-stufe, in which occur a great number of equivalent or identical species. This fauna is entirely unlike anything in the Mississippian province of the United States, but some of our western faunas resemble it.

Fossils are usually abundant and well preserved wherever the Upper Carboniferous limestone is found. The character of this fauna is shown by the following list of the species collected at Pybus Bay, which has been furnished by Dr. Girty:

Zaphrentis ? sp.
Fenestella sp.
Rhombopora sp.
Derbya sp.
Productus aff. P. gruenewaldti Krot
Productus aff. P. humboldti D'Orb
Productus aff. P. timanicus Stuck
Productus aff. P. lineatus Waagen
Productus aff. P. mammatus Keys.
Productus sp.
Rhynchopora aff. R. geinitziana Tscherny.
Spirifer arcticus Houghton
Spirifer aff. S. allatus
Spirifer n. sp. aff. S. marcoui
Spirifer n. sp. aff. S. dieneri Tscherny.
Squamularia sp.
Hustedia sp.
Spiriferina aff. S. cristata Schlot.
Cleiothyris sp.
Camarophoria margaritovi Tscherny.
Camarophoria aff. C. purdoni Davidson
Dielasma sp.
Cryptacanthia aff. C. compacta W. & St. J.
Aviculipecten sp.

In the faunas of the Halleck Harbor section Dr. Girty reports both the upper and lower series of the Gschel-stufe or upper Carboniferous faunas to be represented. This section, which is located on the north side of Saginaw Bay, Kuiu Island, follows:

		Feet
b	Light-gray limestone, locally cherty; fossils abundant	450±
a.	Black carbonaceous shales, with interbedded, dark, calcareous sandstones, arranged in belts, in which shales and sandstones alternately predominate	125+

At one point the shales and sandstones of division *a* are seen to pass along the bedding directly into cherts similar to those of Pybus

Bay. The fauna of this lower division of the section comprises the following species:[1]

Fusulina aff. F. longissima Moell.
Crania sp.
Schizophoria ? sp.
Derbya aff. D. robusta Hall
Chonetes sp.
Chonetes aff. C. trapezoidalis Waagen
Productus aff. P. humboldti D'Orb.
Productus aff. P. porrectus Kut.
Productus aff. P. semireticulatus Martin
Productus aff. P. schrenki Stuck
Productus aff. P. koninckianus Vern.
Productus cora D'Orb
Spirifer aff. S. ufensis Tscherny.
Spirifer cameratus Tscherny. non Martin ?
Squamularia n. sp.
Martiniopsis sp.
Rhynchopora aff. R. geinitziana Tscherny.
Dielasma sp.
Streblopteria sp.
Aviculipecten aff. A. mccoyi M. and H.
Aviculipecten, 2 spp.
Entolium aff. E. aviculatum Meek.
Solenopsis ? sp.

In the upper division, *b*, occur the following species:

Zaphrentis ? sp.
Stenopora sp.
Crinoid fragments
Streptorhynchus aff. S. pelargonatum Schlot.
Chonetes, 2 spp.
Productus aff. P. timanicus Stuck.
Productus aff. P. aagardi Toula.
Productus aff. gruenewaldti Stuck.
Productus aff. P. humboldti D'Orb.
Productus aff. P. mammatus Keys.
Productus aff. P. lineatus Waagen
Productus aff. P. occidentalis Newberry
Productus sp.
Spirifer aff. S. alatus Schlot.
Spirifer aff. S. blasii Vern.
Spirifer arcticus Houghton
Spirifer n. sp. aff. S. marcoui Waagen
Spirifer aff. S. dieneri Tscherny.
Spiriferina aff. S. cristata Schlot.
Squamularia sp.
Cleiothyris sp.
Camarophoria margaritovi Tscherny.
Camarophoria aff. C. purdoni Davidson
Rhynchopora aff. R. nikitini Tscherny.
Rhynchopora aff. R. geinitziana Tscherny.
Dielasma sp.

Professor Schuchert published some notes on a collecton of Carboniferous fossils from a locality near this section in 1896. The fossils were referred to Schuchert by Dr. Dall and Mr. J. A. Becker, and were collected near Point Cornwallis, which is about one mile from Halleck Harbor. Two of these, *Spirifer* sp. undet. and *Productus longispinus* var. *alaskensis* Schuchert, are reported to come from a yellow sandstone. The appearance of the fossils indicates that they came from a siliceous band in the limestone of the section.

[1] Determined by Dr. G. H. Girty.

There appears to be no yellow sandstone member in the Saginaw Bay section. The remainder of the fossils reported by Schuchert are from a sandstone, "burnt-umber in color," which probably represents a portion of division *a* of the above section. The fossils reported by Schuchert from this "burnt umber" sandstone are:

Productus sp. undt. A	Spirifer duplicicostatus Phillips
Productus sp. undt. B	Spirifer pinguis Sowerby
Orthothetes crenistria (Phillips)	Spirifer condor d'Orbigny

The Upper Carboniferous limestone is terminated above by a Mesozoic limestone which rests unconformably on it. It is separated from the Lower Carboniferous series of Freshwater Bay by a series of cherts, dark shales, and sandstones of undetermined thickness. This limestone has a wide distribution in Alaska. In southeastern Alaska it is known on Admiralty, Kuiu, and Kupreanof islands. In the interior of Alaska the fauna of this limestone has been found in the Copper River basin by Mendenhall and Schrader,[1] and in the White River basin by Brooks.[2] The same fauna occurs on the Yukon, at the mouth of Nation River, nearly 700 miles northwest of the Kuiu Island and Pybus Bay localities. It has not been found, however, north of the Arctic circle. It is absent from the collections of both Collier[3] and Schrader[4] from northern Alaska. The writer found no trace of it in the Porcupine River section in northeastern Alaska.

In the United States the formation bearing the nearest resemblance faunally and stratigraphically to the Upper Carboniferous limestone of southeastern Alaska is the McCloud limestone of northern California. In a report on a collection of fossils from the McCloud limestone published by Mr. Diller attention is called to the similarity of the two faunas by Dr. Girty, who suggests that it is such "as to indicate the extension of this fauna and possibly of the earlier Carboniferous faunas of the California province to this region."[5] The thickness of the McCloud limestone has been estimated at from 1,000[6]

[1] *Professional Paper No. 15*, U. S. Geological Survey, 1903, p. 46.

[2] *Twenty-first Annual Report*, U. S. Geological Survey, Part 2, 1900, p. 359.

[3] *Bulletin No. 278*, U. S. Geological Survey, 1906, pp. 22–26.

[4] *Professional Paper No. 20*, U. S. Geological Survey, 1904, pp. 70, 71.

[5] *American Journal of Science*, Fourth Series, Vol. XV (1903), p. 351.

[6] *Geology of California*, Vol. I, p. 326.

to 2,000[1] feet. A thick series of shales and sandstones, with some conglomerates and calcareous lenses, underlies it.[2] Its nearest faunal relationship, like that of the Alaskan Upper Carboniferous limestone, is with the European and Asiatic province. The McCloud limestone has generally been regarded of Upper Carboniferous age.[3] By Tschernyschew it is correlated with the Upper Carboniferous or Uralian of Russia.[4]

It is very probable that representatives of the Upper Carboniferous limestones of Pybus Bay and Kuiu Island will be found in the Cache Creek[5] series of British Columbia. The data thus far published on these rocks show only that a considerable thickness of Carboniferous limestones[6] is present in British Columbia.

SUMMARY

The Silurian is represented by a limestone series probably 3,000 feet thick, holding faunas whose nearest equivalents in eastern America are the Niagaran and Guelph faunas. A series of beds aggregating several thousand feet in thickness precedes the beds known to be of Silurian age, and represents either Silurian or earlier horizons.

Lower, Middle, and Upper Devonian faunas are present in southeastern Alaska, the first resting upon beds of igneous origin. The total thickness of the Devonian is unknown. In the northern part of the region the Upper Devonian appears to be represented in part by beds of igneous origin. A limestone series about 470 feet in thickness forms the lowest lithologic series of the Devonian. *Spirifer disjunctus* and *Productella hallana* Wal. characterize the Upper Devonian fauna. Two species of *Hercynella* are the most abundant forms in the basal Devonian.

Limestones resembling somewhat the Mississippian in their fauna represent the Lower Carboniferous. These have a thickness of about

[1] *Journal of Geology*, Vol. II, p. 600. [2] *Ibid.*

[3] *Paleontology of California*, Vol. I, pp. 326, 327; *Journal of Geology*, Vol. II (1894), pp. 600, 601.

[4] *American Journal of Science*, Fourth Series, Vol. XXII (1906), p. 39; *Mémoire du Comité géologique*, Vol. XVI (1902 [1903]), pp. 433–51.

[5] *Bulletin of the Geological Society of America*, Vol. XII (1900), p. 70.

[6] *Ibid.*, p. 71.

1,500 feet. The highest member of the Paleozoic section in southeastern Alaska is a limestone of Upper Carboniferous age, probably the equivalent of the Gschel-stufe. At the only locality where the top of the Upper Carboniferous has been definitely located a limestone of Mesozoic age rests unconformably upon it. A series of beds, mostly limestones, having a thickness of not less than 800 feet, represents the Upper Carboniferous portion of the section.

The several faunas show comparatively little resemblance to the faunas of eastern America, while the similarity to the European and Asiatic faunas is in some cases very marked.

CONTRIBUTIONS TO THE PLEISTOCENE FLORA OF NORTH CAROLINA[1]

EDWARD W. BERRY
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INTRODUCTION

During the summer of 1906, while engaged in a geological reconnaissance in North Carolina under the auspices of the Geological Survey of that state, two very interesting plant-beds of Pleistocene age were discovered, from which about forty different species of plants were collected. It is planned to describe and to fully illustrate these, together with future collections which it is hoped will be made, in a systematic volume devoted to the fossil remains of North Carolina; but, since it will be several years before this plan can be consummated, it seems desirable to publish a brief preliminary account of these plants, in so far as they have been determined, because of their by no means inconsiderable interest. To the geologist their chief interest is their bearing upon Pleistocene climates and their circumstantial evidence as to the very slight lapse of time, from a geological point of view, since glacial conditions came to a close. For the botanist they tend to show that some of the main elements in our present coastal plain flora, especially the arborescent forms, were already well defined in Pleistocene times, and that, while very likely a considerable part of the endemic herbaceous flora of the coastal plain has been differentiated in postglacial times, this theory cannot be extended to include many of the arborescent forms. The bulk of the following species are from a deposit on the Neuse River in Wayne County which I regard as of estuarine origin, laid down in post-glacial times, although it is quite possible that we have to deal with river deposits.[2]

[1] Published by permission of the North Carolina Geological Survey.

[2] Marine Pleistocene fossils occur near the mouth of the Cape Fear River, and an abundant marine fauna of Pleistocene age has been obtained from several artesian wells in New Hanover and Brunswick counties.

The assumptions on the part of the writer are drawn from the analogy of the Maryland and South Carolina Pleistocene, where an abundant marine fauna has been found. The locality along the Roanoke River will be referred to as Old Mill, and that on the Neuse River as station 850, the latter shown on the United States Engineers' blueprint map of the Neuse River. Citations will be made only of fossil occurrences.

ENUMERATION OF SPECIES

SPERMATOPHYTA

GYMNOSPERMAE

Coniferales

PINUS RIGIDA Mill.

Penhallow, *Transactions of the Royal Society of Canada*, Vol. X (1904), sec. 4, p. 69.

Characteristic leaves of this species, which are stout and stiff, some of them still in fascicles of three with the sheaths preserved, occur at station 850.

In the modern flora this species ranges from New Brunswick to Georgia, and west to Ontario and Kentucky, in dry sandy or rocky soil. It is a dominant form in the so-called "pine barrens" of New Jersey, and ranges farther north than do most of the members of the North Carolina Pleistocene flora. Wood has been recorded by Penhallow (*loc. cit.*) from a well-boring at Ithaca, N. Y.

The European Pleistocene contains several species based on foliage, cones, seeds and wood. In America *Pinus strobus* L. has been recorded from New Brunswick and Maryland, and *Pinus echinata* Mill from Maryland.

TAXODIUM DISTICHUM (L.) L. C. Rich.

Holmes, *Journal of Elisha Mitchell Society* for 1884-85, p. 92 (1885).

Berry, *Torreya*, Vol. VI (1906), p. 89.

Hollick, Maryland Geological Survey, *Pliocene and Pleistocene* (1906), p. 218, Plate 68.

Cypress swamps seem to have been a feature of the Pleistocene of the Atlantic coast. Several such, with stumps, knees, cones, and seeds, have been described from Maryland, and I am able to record another from near Rehobeth, Dela.[1]

[1] Communicated by Dr. C. K. Swartz.

Holmes (*loc. cit.*) records stumps up to six feet in diameter in a dark stiff clay beneath 18–20 feet of loam, laminated sands and clays, and marls, a few miles below New Bern on the Neuse River.

At station 850 were found many twigs and detached seeds. At Old Mill the twigs are common, and a rather poor cone impression was collected together with an unmistakable staminate ament.

ANGIOSPERMAE

Juglandales

HICORIA GLABRA (Mill) Britt.

Berry, *Torreya*, Vol. VI (1906), p. 89.

Occurrence based on a flattened nut and several husks from station 850. This species has been previously recorded from the Pleistocene of Virginia (nuts), and a small nut not specifically determined is recorded by Hollick from Maryland. The latter author also describes leaves of apparently this species under the name of *Hicoria pseudo-glabra* from the basal Pleistocene (Sunderland) of Maryland.

HICORIA OVATA (Mill) Britt.

Determination based on two incomplete terminal leaflets from station 850 which resemble this species more closely than they do those of any other modern hickory. In the living flora this species ranges from Quebec to Florida.

HICORIA SP. cf. *microcarpa* (Nutt.) Britt.

A hickory nut of larger size, much flattened and with a thin, apparently tardily dehiscent, husk was found at station 850. As yet it has not been satisfactorily correlated with any of the existing species.

Salicales

SALIX SP.

A single leaf of a willow was found at station 850. It has not been possible to satisfactorily determine its specific relations. The poplars which are well represented by three species of leaves in the Maryland Pleistocene have not yet been found in North Carolina.

Fagales

CARPINUS CAROLINIANA Walt.

Represented by numerous leaves from station 850. Similar remains are recorded from the basal Pleistocene of Maryland by

Hollick under the name *Carpinus pseudo-caroliniana*. The living *Carpinus orientalis* L. K. and *betulus* L. have been recorded from the Italian Pleistocene.

BETULA NIGRA L.

Knowlton, *American Geologist*, Vol. XVIII (1896), p. 371.

This species was very common at station 850, the remains including many leaves and some fragments of bark. Leaf impressions were also common in the clays at Old Mill. Recorded by Knowlton (*loc. cit.*) from the glacial terraces at Morgantown, W. Va.

The genus first appears in the Dakota sandstones, occurring also in the higher Cretaceous of North America and Greenland. It is largely developed in the Eocene, with over a dozen American species, the first European forms occurring at this horizon. Abundantly represented by numerous species in the Oligocene, Miocene, and Pliocene. Of the living forms *Betula lutea* Michx. has been recorded from the American, and *Betula nana* L. and *alba* from the European Pleistocene.

BETULA PSEUDO-FONTINALIS sp. nov.

Leaves in appearance very similar to those of the western *Betula fontinalis* of Sargent occur at station 850. The name given implies nothing more than the resemblance in leaf-form. This species may be characterized as follows: leaves ovate, with a broad truncate or rounded entire base; unusually long petiole and sparse secondary venation; margin indifferently serrate or dentate above.

FAGUS AMERICANA Sweet.

Berry, *Torreya*, Vol. VI (1906), p. 88.

Hollick, Maryland Geological Survey, *Pliocene and Pleistocene* (1906), p. 226. *Fagus ferruginea* (Michx.) Lesq.: *American Journal of Science*, Vol. XXVII (1859), p. 363; *Geology of Tennessee* (1869), p. 427, Plate 7 (K), Fig. 11. *Fagus ferruginea* Ait.: Knowlton, *American Geologist*, Vol. XVIII (1896), p. 371.

Leaves, nuts, and husks of this species are common at station 850. The beech is one of the commonest Pleistocene forms, and leaves, nuts, or husks have previously been recorded from both the oldest (Sunderland) and the youngest (Talbot) Pleistocene formations of Maryland, and from the Pleistocene of Tennessee, Virginia, and West Virginia.

QUERCUS PHELLOS L.

Leaves of the willow oak are common at station 850.

QUERCUS ALBA L.

Penhallow, *Transactions of the Royal Society of Canada*, Vol. X (1904), sec. 4, p. 74.

The leaves of the white oak are fairly common at station 850. Both leaves and wood are recorded by Penhallow from the Don River beds of Canada, and probably the same species under the name of *Quercus pseudo-alba* is recorded by Hollick from the Sunderland of Maryland.

QUERCUS LYRATA Walt.

Several leaves, together with four characteristic specimens of the acorns, of this species were found at station 850.

QUERCUS PALUSTRIS Du Roi.

Occurrence based on leaves from station 850.

QUERCUS PREDIGITATA sp. nov.

Leaves of the type of those of the Spanish oak—to which, however, it has seemed best to give a new name, since it is very probably the ancestral form, not only of this species, but of *Quercus pagodaefolia* (Ell.) Ashe as well—are abundantly represented at station 850. The leaves show gradations between *digitata* and *pagodaefolia*. Probably the same species is recorded by Knowlton from the glacial terraces at Morgantown, W. Va., under the old name *Quercus falcata* Michx.

QUERCUS ABNORMALIS sp. nov.

An abnormal oak leaf, bifid, with two linear lobes about one inch across. Based on a single specimen with the characteristic venation of *Quercus* from station 850. Leaf narrow, elongated, coriaceous; the blade divided about half-way up into two divergent lobes; margins entire.

QUERCUS MARYLANDICA Muench.

Several leaf specimens were collected at station 850.

QUERCUS NIGRA L.

Several leaf specimens from station 850.

QUERCUS PRINUS L.

Leaves fragmentary for the most part, but common, station 850.

QUERCUS PLATANOIDES (Lam.) Sudw.

Several leaf specimens from station 850. It is, of course possible —I might say, probable—that the leaves of this and the preceding represent the variable leaves of their common Pleistocene ancestor, not yet differentiated into dry and moisture loving forms.

QUERCUS PRINOIDES Willd.

Leaves which apparently represent this species occur at station 850, although it is impossible to determine their exact relation to the two preceding forms.

ULMUS ALATA Michx.

Several leaves of this modern southern type were found at station 850. Two species of *Ulmus* are known from the Sunderland of Maryland; *Ulmus betuloides* Hollick, possibly representing the modern *Ulmus americana* L., and *Ulmus pseudo-racemosa* Hollick, representing the modern *Ulmus racemosa* Thomas. The latter also occurs at Morgantown, W. Va., and in the Don River deposits of Canada, where it is associated with *Ulmus americana*.

PLANERA AQUATICA (Walt.) J. F. Gmelin.

This southern type in the modern flora is represented by two or three rather unsatisfactorily determined leaves from station 850. The related, if not identical *Planera ungeri* Ettings is recorded from the Sunderland of Maryland.

Ranales

BERBERIS SP.

A single leaf, apparently a barberry, but not specifically determinable, was found at station 850.

Rosales

LIQUIDAMBAR STYRACIFLUA L.

Hollick, *Bulletin of Torrey Club*, Vol. XIX (1892), p. 331.

Knowlton, *American Geologist*, Vol. XVIII (1896), p. 371.

Liquidambar europaeum Al. Br., Lesq.: *Proceedings of U. S. National Museum*, Vol. XI (1888), p. 36.

The sweet or red gum is sparingly represented at station 850 by two or three fragmentary leaves and one flattened fruit-head. Previously recorded from Morgantown, W. Va., by Knowlton, and from Bridgeton, N. J., by Lesquereux and Hollick. I should expect this

species to be more common in the North Carolina Pleistocene than it is. Its rarity, however, may be one of the exigencies of preservation, since I have noticed that the modern gum leaves decay much more rapidly than do most other leaves, judging by their comparative state of preservation in the recent leaf-rafts and leaf-beds along the North Carolina rivers.

PLATANUS OCCIDENTALIS L.

Knowlton, *American Geologist*, Vol. XVIII (1896), p. 371.

Penhallow, *Transactions of the Royal Society of Canada* (II), Vol. II (1896), sec. 4, pp. 68, 72.

Platanus aceroides Göpp.: Hollick, Maryland Geological Survey, *Pliocene and Pleistocene* (1906), p. 231, Plates 73, 74.

Fragmentary leaves of this species were common, and one flattened "buttonball" was found at station 850.

This seems to have been one of the common types of the Pleistocene. Recorded from the Sunderland, or oldest Pleistocene, of Maryland, as well as in the interglacial Don River deposits of Canada and the glacial terraces at Morgantown, W. Va. The Carolina leaves average somewhat smaller than do those of the modern tree.

RUBUS SP.

Based on a small branch with characteristic prickles, found at station 850.

MALUS CORONARIAFOLIA sp. nov.

Leaves triangularly ovate with acute apex and rounded base, 4^{cm} by 3.1^{cm}, with four or five incised lobes on each side, the margins finely salient-serrate. Based on leaves very like those of the American crab apple, *Malus coronaria* (L.) Mill, found at station 850. Besides these leaves there are others somewhat resembling the modern *Malus angustifolia*, but not yet positively determined.

CRATAEGUS SPATHULATOIDES sp. nov.

Based on leaves like those of the modern small-fruited haw, *Crataegus spathulata* Michx; which they resemble so closely that further specific characterization is unnecessary. Collected at station 850.

CRATAEGUS COCCINEAFOLIA sp. nov.

Based on leaves and thorns preserved in the lignitic layers, and so like those of the modern scarlet thorn, *Crataegus coccinea* L., that further specific characterization is unnecessary at this time.

It is probable that both this and the preceding still exist, but since the modern thorns have been segregated into such a maze of species, it was not thought profitable to attempt any closer identification of these two Pleistocene forms.

Sapindales

ILEX OPACA Ait.

Hollick, *Bulletin of Torrey Club*, Vol. XIX (1892), p. 331.

Based on two characteristic leaves from station 850. Recorded by Hollick along with *Ilex cassine* L. from Bridgeton, N. J.

The genus is an old one, ranging back to the Mid-Cretaceous, and apparently somewhat composite in character. A species of the Prinos section is recorded from the Pleistocene of Kentucky, and the genus is also represented in the European Pleistocene.

Rhamnales

VITIS SP.

This occurrence is based on a tendril preserved at station 850.

Grapes were apparently common during the Pleistocene, although heretofore represented only by their very characteristic seeds, which have been recorded by the writer from the Virginia Pleistocene, and by Hollick from four different localities in the Maryland Pleistocene. Two Pleistocene species are recorded from Europe.

Thymeleales

PERSEA PUBESCENS (Pursh) Sargent.

This southern swamp form is represented by two leaves from station 850.

Umbellales

NYSSA BIFLORA Walt.

Berry, *Torreya*, Vol. VI (1906), p. 90.

Hollick, Maryland Geological Survey, *Pliocene and Pleistocene* (1906), p. 235, Plate 69, Fig. 5.

Nyssa caroliniana Poir: Hollick, *Bulletin of Torrey Club*, Vol. XIX (1892), p. 331.

North Carolina representation includes leaves from station 850 and seeds from Old Mill. Previously recorded from the late Pleistocene of Virginia and Maryland, being represented by both leaves and seeds in the latter state. Leaves have been recorded from Bridgeton, N. J., and the writer has recently collected the seeds in the clays at Fish House, N. J.

Ericales

XOLISMA LIGUSTRINA (L.) Britt.

Hollick, Maryland Geological Survey, *Pliocene and Pleistocene* (1906), p. 236, Plate 69, Fig. 6.

Fossil forms of this type of leaf are usually referred to the genus *Andromeda* of Linnaeus, and many species are recorded, ranging from the Mid-Cretaceous to the present. Lesquereux records two species (*dubia* and *vaccinifoliae affinis*) from the Pleistocene of Somerville, Tenn. The present species was found at station 850. It has been previously recorded from the late Pleistocene (Talbot) of Maryland.

DENDRIUM PLEISTOCENICUM sp. nov.

Based on leaves from station 850. They are of coriaceous texture, and are identical with those of *Dendrium hugeri*, which has been separated by Small from the old species *Dendrium buxifolium* (Berg.) Desv., in which the leaves are smaller.

It seems likely that the modern *Dendrium hugeri*, which is a form of the mountains of western North and South Carolina, is directly descended from this Pleistocene form, and that *Dendrium buxifolium*, which is a "pine-barren" form with reduced leaves, and which ranges from New Jersey to Florida, is a later specialization in that habitat.

VACCINIUM CORYMBOSUM L.

Hollick, Maryland Geological Survey, *Pliocene and Pleistocene* (1906), p. 236, Plate 69, Figs. 7–9.

Specimens of leaves of this species occur both at station 850 and at Old Mill. Previously recorded from the late Pleistocene (Talbot) of Maryland.

VACCINIUM SPATULATA sp. nov.

Based on spatulate leaves of this generic type found at station 850. Length 2.4^{cm}, width 1.2^{cm}. Somewhat coriaceous with two or three remote camptodrome secondaries on each side.

CONCLUSIONS

Attention is arrested by the remarkable development of the oaks in this flora, there being eleven species in all, or nearly 29 per cent. of the known flora; and if it be objected that some of the determinations, such as the recognition of *prinus*, *prinoides*, and *platanoides*, will not stand, there still remains an unusually large showing, possibly to be explained by the fact that oak leaves are more coriaceous and resist maceration better than do most leaves.

It will be seen at a glance that the enumerated flora as given above contains no boreal or even cool temperate elements. All of the species which in the modern flora range northward into New England or Canada also range southward to Georgia and Florida, with but two exceptions—*Pinus rigida*, whose present southern range is Virginia, and *Quercus prinoides*, whose present southern limit is North Carolina. Southern Delaware and Maryland mark the northern limit of *Taxodium distichum;* New Jersey marks the northern limit of *Quercus lyrata, digitata, nigra, Nyssa biflora*, and *Dendrium;* while *Quercus phellos* and *marylandica* do not get beyond Long Island, and *Liquidambar* dies out in Connecticut. On the other hand, *Ulmus alata* does not get north of Virginia, and *Persea pubescens* and *Planera aquatica* do not get north of North Carolina.

There are nine distinctly swamp and low river-bank forms, two additional forms of low moist woods besides *Liquidambar* and *Platanus*, which make their best growth in humid wooded regions. The forms which in the living flora are denizens of dry sandy or rocky soils are *Pinus rigida, Quercus phellos, digitata, nigra, prinoides*, and *marylandica*.

While it is always perilous to estimate the temperature in degrees from fossil faunas or floras, and it would be rash indeed to assert that, since some of these forms do not range above North Carolina in the living flora, the temperature of the Pleistocene in this region would have a minimum of 40° to 44°. However, from the floral grouping as a whole I think it may safely be concluded that the temperatures were not lower than they are at the present time in the same latitude, and, if anything, they were slightly higher, with as great humidity as prevails at the present time in the coastal plain of North Carolina.

These results agree with those arrived at by Pugh[1] from a study of the Mollusca from the Pleistocene of South Carolina. Additional facts pointing to the same general conclusion are the former northward extension of *Taxodium*, and the occurrence of *Planera aquatica* in the Pleistocene of Maryland. That these floras did not flourish in mild interglacial periods is indicated by their association in Maryland with ice-borne bowlders of considerable size, the origin of some of which has been traced, the direction of movement discrediting forces other than those of ice-action. A further fact is the occurrence of several of these species in the West Virginia glacial terraces. Some of these terraces contain remains of the musk-ox and other pronounced boreal types, and are undoubtedly of glacial origin. Those with fossil plants are not so satisfactory, as they contain few species of northern affinities, and might be taken to illustrate interglacial conditions, although they do not indicate as mild a climate as do the fossiliferous interglacial beds in the valley of the Don, near Toronto, Canada. These considerations somewhat weaken their evidence in this connection. They are here denominated as "glacial," following the original description by I. C. White and Knowlton, with the reservation that close stratigraphical studies may subsequently show that the plant-bearing terraces differ in age from those with boreal animal remains, as the contained flora in a measure indicates, although not altogether inconsistent with the published view of their glacial age.

To be sure, the North Carolina deposits were many miles south of the terminal moraine, and the local ice which may have been developed, while it proved equal to the task of transporting bowlders, did not exercise any considerable effect upon the temperatures of the lowlands. Cobb has suggested[2] that the cobbles found along the "banks" of the Carolina coast were transported by icebergs from New England during periods of maximum glaciation and are not of local origin. By implication this theory might include all the erratics in the marine Pleistocene of the southern coastal plain. Such a conclusion seems, however, extremely improbable.

[1] G. T. Pugh, *Pleistocene Deposits of South Carolina*, Thesis, Vanderbilt University, 1905.

[2] C. Cobb, *Journal of Elisha Mitchell Society*, Vol. XXII (1906), p. 18.

We know that the land was low and that the country was densely wooded, with a high humidity, all of which are factors that ameliorate temperatures, so that persistent ice in comparatively low latitudes, if present at all, seems to have been almost entirely a question of moderate cooling in the highlands, combined with unbalanced precipitation, while the climate of the low-lying coastal plain, even as far northward as Maryland, did not differ greatly from what it is at present.

THE GIRDLES AND HIND LIMB OF HOLOSAURUS ABRUPTUS MARSH

S. R. CAPPS, JR.
University of Chicago

The specimen described below, in the Paleontological Collection of the University of Chicago, was collected during the summer of 1903 by a University of Chicago paleontological expedition. The complete skeleton was discovered by Dr. E. B. Branson and collected by himself and Professor Williston. Thanks are due to Dr. Williston for permission to study this excellent specimen.

The specimen is of peculiar interest in that it is probably the most complete one of a mosasaur ever collected, almost every bone lying in its original position with relation to the rest of the skeleton. Furthermore, it belongs to the hitherto very imperfectly known form of *Holosaurus abruptus* Marsh, and the undisturbed condition of the skeleton offers an opportunity for clearing up a number of doubtful points. Besides this remarkable specimen, a complete pelvic girdle of the same species was found at the same time, with the bones spread out in their original relations to one another. From the study of these two specimens it was determined: (1) that the ilium lay below the third pygal vertebra, and not below the first, as usually figured, and that it had a nearly vertical position to the vertebral column, instead of having a strong backward slope; (2) that there was a firm symphysis of both the ischia and of the pubes, as shown by the position of these bones (Fig. 2); (3) that there was an interclavicle bone present (Fig. 1). The rear paddle of the mosasaur, moreover, has so far been very imperfectly known. It was figured by Marsh in 1880 for *Platecarpus*, and by Osborn much later for *Tylosaurus dyspelor*, but neither specimen was perfect, and both are of species different from that described below (Fig. 3).

The pectoral girdle of this specimen is very perfectly preserved (Fig. 1). Lying between the coracoids there was found a thin,

bladelike bone, the interclavicle. In 1880 Marsh[1] stated: "In *Holosaurus* there appears to have been a partially ossified mesosternum;" and in 1889 Dollo[2] mentioned the presence of an interclavicle

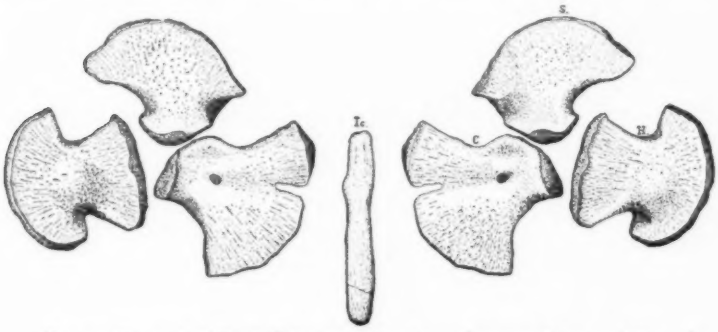

FIG. 1.—Pectoral girdle of *Holosaurus abruptus*. One-seventh natural size. *Ic*, interclavicle; *c*, coracoid; *s*, scapula; *H*, humerus.

in *Plioplatecarpus*. Williston[3] discovered the existence of this element in *Platecarpus* in 1899, but up to the present time it has never been figured. The interclavicle in this specimen is slender, rounded

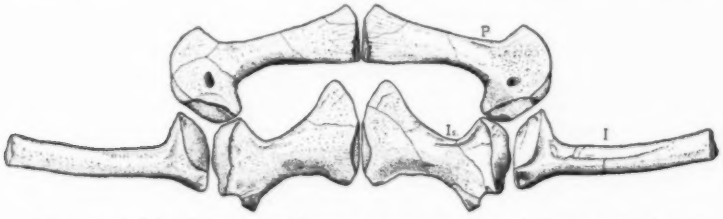

FIG. 2.—Pelvic girdle of *Holosaurus abruptus*. One-sixth natural size. *P*, pubis; *Is*, ischium; *I*, ilium.

laterally at both ends, and differs from that described for *Platecarpus* in that it has no apparent articular facets at the anterior end.

The calcified sternum of the specimen is preserved in the chalk, but no description of this will be attempted in the present article, as

[1] *American Journal of Science*, Vol. XIX (1880), p. 841.

[2] *Bull. Soc. Belg. Geol. Pal. Hyd.*, III (1889), 286.

[3] *Kansas University Quarterly*, Vol. VIII, No. I (January, 1899), p. 39.

considerable further study will be necessary for the proper working-out of this portion of the skeleton.

The *scapula* resembles very closely that of *Platecarpus ictericus*,[1] being thinned and flattened above, with a truncate margin for cartilaginous attachment. Below, the bone is thickened for articulation with the coracoid and humerus.

The *coracoid* also is remarkably like that of *Platecarpus*, the only essential difference being the less deep emargination. This species is referred with great certainty to *Holosaurus abruptus* by Williston after a careful examination of the type specimen in the Yale collection—a specimen which he himself collected. The emargination of the coracoid is therefore proven to be an individual, and not a generic character. The close resemblance of the different elements of the skeleton to that of *Platecarpus* make it seem certain that this specimen must ultimately be referred to that genus, but there are a number of differences between this specimen and any described species of *Platecarpus*. The name *Holosaurus abruptus* will therefore be used provisionally until the specimen is mounted and available for critical comparison.

The ilium.—The ilium is a shaftlike bone, expanded proximally. From the relation in which the bones of the two sides were found it is evident that the vertebral end was approximated in life to the end of the transverse process of the third pygal vertebra, though evidently not attached to it. The relations of the bones, as found, also show that the ilium had a nearly vertical position. Proximally the bone is expanded and thickened, with a continuous facet for articulation with the ischium and pubis, and for the acetabulum. The bone resembles most closely that of *Platecarpus*.

The ischium.—The ischium is a very broad, flat bone, laterally expanded at either end. The acetabular end has facets for articulation with the ilium and pubis, and an outwardly directed face for the acetabulum. Behind the acetabulum, and slightly separated from it, is a thin process with a roughened end for cartilaginous attachment. The shaft of the bone has a rounded, thickened ridge on its lower side, and is slightly concave above. The distal end has a very broad, thin lateral expansion in front. The shaft, at its thickened portion,

[1] *University Geological Survey of Kansas*, Vol. IV, p. 184.

shows a sub-triangular facet for a firm symphysis with the opposite ischium.

The pubis is much like that of *Platecarpus*. It is a thin bone, broadly rounded at the acetabular end, the posterior edge of which ends in facets for the acetabulum, and for articulation with the ilium and ischium. The pubic foramen is placed similarly to that of *Platecarpus*. The lower end of the bone is thin and somewhat expanded, and shows a roughened face for symphysis with the opposite pubis.

Femur.—The femur is a heavy, stout bone, somewhat expanded proximally and terminating along the whole upper border in an articular face which is thickened anteriorly and thinned posteriorly. The trochanter, on the anterior side, is directed upward and inward. The distal end of the bone is more expanded than the proximal, and has a much thickened oval face for articulation with the tibia, and a thinner one for the fibula.

Tibia.—The tibia is a short, stout bone, expanded and much thickened at the proximal end, and having a large, oval face for articulation with the femur. The anterior margin of the bone is deeply concave, and the posterior margin is longer, and less deeply concave. The distal end is fan-shaped, thinned anteriorly and posteriorly, and thickened centrally. It ends in a flat facet for articulation with the large tibial tarsal bone.

In Plate VII of Williston's work on the Mosasaurs,[1] Figs. 1 and 2 are referred to the radius of a doubtful species of *Platecarpus*, but these bones are doubtless tibiae of *Holosaurus abruptus*, to which genus they have already been referred by Williston.

Fibula.—The fibula is a thin, flat bone, expanded laterally at both ends. At the proximal end is the articulation for the femur, facing forward and upward. The anterior margin of the bone is concave throughout and is shorter than the strongly concave posterior margin. Distally the bone is fan-shaped, and bears articular faces for the two upper tarsals.

Tarsus.—The tarsus is composed of three bones, a large and two smaller, posterior to it, all of which are thin and flat. The large bone has two articular faces above, for the tibia and fibula, that for the

[1] *University Geological Survey of Kansas*, Vol. IV, Plate LVII.

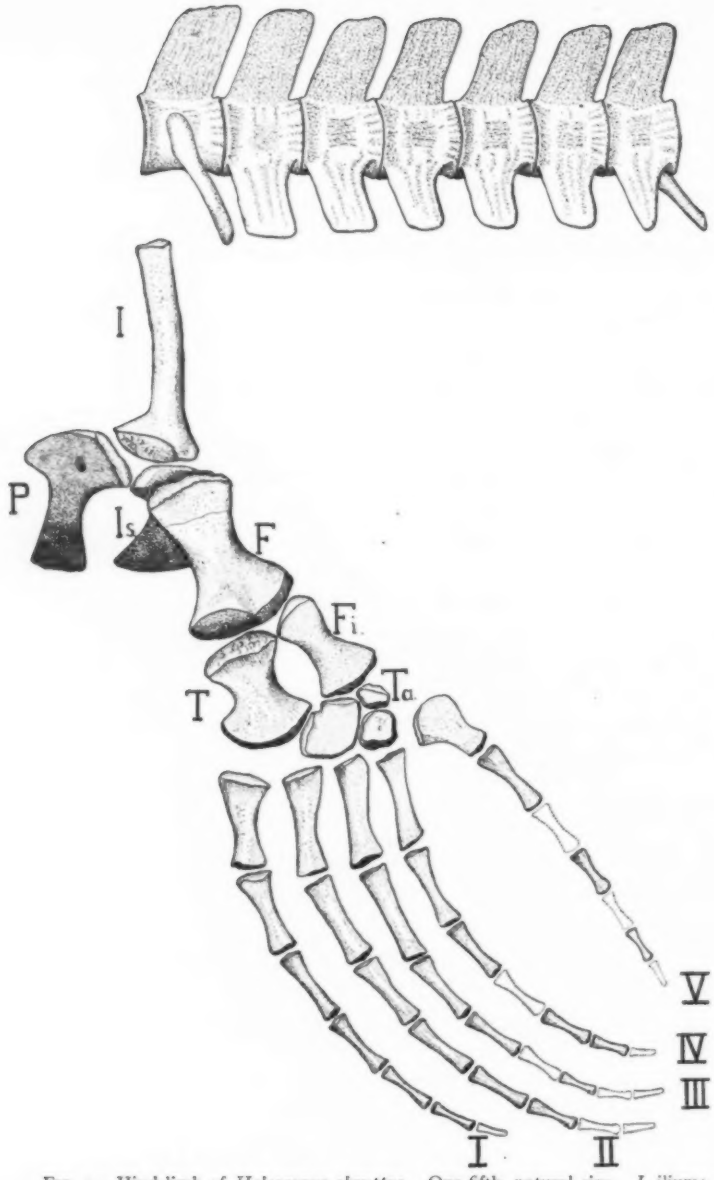

FIG. 3.—Hind limb of *Holosaurus abruptus*. One-fifth natural size. *I*, ilium; *P*, pubis; *Is*, ischium; *F*, femur; *T*, tibia; *F*, fibula; *Ta*, tarsus. Ilium found lying opposite the third pygal, the fourth vertebra of the series, as figured.

former sloping obliquely forward, and for the fibula obliquely backward, the two making an angle of something more than 90°. These two faces are separated by a rounded notch. The distal edge is a wide curve, and articulates with the second and third metatarsals and the other two tarsals. The two smaller tarsals lie one above the other, behind the large one. The upper one is the smallest, and articulates with the fibula, the other two tarsals, and the fifth metatarsal. The lower of the two smaller tarsals articulates with the other two tarsals, and with the fourth and fifth metatarsals.

Metatarsals.—The first metatarsal is a stout bone, broadly expanded and thickened proximally, with a large, flat surface for the tibial articulation. This face slopes obliquely backward. Toward the middle the bone is constricted, and the posterior margin is deeply concave, and is shorter than the more gently concave anterior margin. The distal end is slightly expanded and ends in a suboval, flat articular facet.

The second metatarsal is more slender than the first. Its proximal end is expanded laterally, with the anterior edge thicker than the posterior. The articular face is directed forward and upward. The anterior margin of the shaft is thick and only slightly concave, while the posterior margin is thinner and rather deeply concave in the center. The distal end is slightly expanded, and has a subtriangular articular face.

The third metatarsal is the longest of the five. Its somewhat expanded proximal end terminates in a suboval face for articulation with the largest tarsal bone. The anterior margin of the shaft is almost straight, while the posterior margin is deeply convex toward the distal end, which terminates in a backward sloping articular face. The two articular faces are subparallel.

The fourth metatarsal is smaller and more slender than the three preceding. Its proximal articulation slopes forward somewhat, and is subparallel with the backward-sloping distal articular face. The bone is somewhat expanded at both ends, and the concavity of the forward margin, though slight, exceeds that of the nearly straight posterior margin.

The fifth metatarsal is a thin, flattened bone, much expanded proximally. The proximal border is edged on the forward and

upper side, by a flat face for articulation with the two smaller tarsals. The inner border is thicker and less strongly concave than the shorter outer border. Distally, the bone is not one-half the width of the proximal end. It is somewhat thickened, and terminates in a convex articular face.

Phalanges.—The first finger has at least six, possibly seven, phalanges, all stout and of a slender hourglass shape. The inner margin has the greater concavity.

The second finger has seven phalanges, shaped much like those of the first finger, with the greater concavity on the posterior margin.

The third finger is of about equal length with the second, and probably had the same number of phalanges, but the bones are somewhat more slender. The posterior margin is more concave and shorter than the anterior.

The fourth finger has about six phalanges which were somewhat thinner and flatter than in the first three fingers. The greater marginal concavity is on the posterior side.

The fifth finger is thin and flat. There were five or six phalanges, all much wider than thick, with the greater concavity on the anterior side. This finger is considerably shorter than any of the others.

The bones of the hind limbs were somewhat intermingled, and partially disarranged, but a careful study of their positions as found in the chalk slab renders any other arrangement than the one given for all save the terminal bones practically impossible.

THE FORMATION OF LEUCITE IN IGNEOUS ROCKS
Continued

HENRY S. WASHINGTON

COMPARISON

In the preceding discussion we have dealt only with norms or ideal rocks, of simple chemical compositions, and with perfectly normative modes composed of a few standard minerals alone. In these the relations are purely chemical, and the order of affinity for silica has been assumed to be invariable. But we have now to consider igneous rocks as they actually exist in nature. In dealing with them the problem becomes much more complex, not only through the introduction of a greater number of chemical and mineral constituents, but on account of the presence of several factors, both intrinsic and extrinsic to the magma or the rock, which may greatly modify our assumedly invariable orders of affinity.

We must remember that few of the standard minerals present in rocks are ever as simple in composition as they are assumed to be in calculating the norm. Thus a purely potassic orthoclase seldom occurs, this mineral almost invariably containing varying, though often small, amounts of soda and lime. Similarly with albite and anorthite, which tend to crystallize together, as well as to contain frequently small quantities of the orthoclase molecule. Leucite usually carries small amounts of soda and lime, while modal nephelite is never a simple, purely sodic, orthosilicate, but invariably contains small percentages of potash, giving rise to a more complex formula. The development in very many rocks of the alferric augites, hornblendes, micas, and other minerals, with numerous chemical constituents and highly complex molecules, is also an important fact to be taken into consideration.

Again, the fact that the crystallization of minerals changes the composition of the remaining fluid portions of the magma must not be lost sight of, and finally the influence of such factors as the mass action of complex mineral molecules, the physical conditions of

cooling, the presence of mineralizers, and so forth, upon the order of affinity are all important elements in the problem. The list of these possibly disturbing factors is a long one, and the established facts of chemistry show that affinities which hold good, or reactions which take place, under certain conditions may be much modified or entirely altered under others.

Bearing these possibilities in mind, we may proceed to the comparison between the actual rocks and our assumed norms. This may be done by plotting the rocks on the same diagram as our theoretical areas, and observing the correspondences and divergences, for which we may again turn to Plate II (p. 270).

The rocks chosen for comparison embrace practically all those known to me which carry modal leucite, whether or not it is present in the norm, and those which show normative but not modal leucite. Some seriously altered rocks are omitted, and only rocks of which superior, trustworthy analyses exist, and of which the norms can be properly calculated, have been selected. With these are also plotted certain rocks which do not carry leucite either in the norm or in the mode, but which are high in potash, as well as a few which are not specially high in potash, but which belong to the same comagmatic regions as leucitic rocks, and are genetically connected with them. The list of the non-leucitic rocks could be increased very greatly, as they form the vast majority of all known rocks; but the plotting of an indefinitely large number would not aid the present discussion, so that only those few are chosen which fall near the leucitic areas or which seem to bear on the problem.

The analyses are taken from Roth's *Tabellen*, from my collection of rock analyses published between 1884 and 1900, from the recent paper on the rocks of the Roman Comagmatic Region, and from numerous analyses published since 1900, of which a collection is being made preparatory to the publication of a supplement to the first. A list of those plotted will be found in the Appendix.

Nearly all of these analyses are plotted on Plate II, the abscissa being the percentage of silica and the ordinate that of potash, both expressed molecularly. The following conventional signs are adopted: Black indicates a persalane rock, green a dosalane, and red a salfemane or dofemane rock. A circle denotes that leucite is present in

the norm, and a square that leucite is not present in the norm. A solid color denotes that leucite is present in the mode, and a simple outline with uncolored interior that leucite is not present in the mode. Thus a solidly colored circle shows that the rock contains leucite both in the norm and in the mode; a solidly colored square, that it contains no normative leucite, but that this mineral occurs modally; an uncolored circle, that, while the norm of the rock shows leucite, none of this has actually developed; and finally, an uncolored square, that the rock is not leucitic, either normatively or modally.

The first general survey of Plate II shows that the general position and drift of the leucite rocks correspond well with the plotted areas of leucitic norms, $L^1O^1N^1$ to $L^9O^9N^9$. A very few fall outside and to the left of these limits, these rocks being without normative leucite, and some to the right of the area $L^9O^9N^9$, these being all normatively leucitic, but modally either leucitic or non-leucitic. The general direction of the axis of this area of the loci of leucitic rocks, or its drift, as it may be termed, is distinctly parallel to that of the inclination of the leucitic areas, especially to that of the lines *ON*.

Again, it will be observed that the abnormatively modal rocks (as regards leucite) lie for the most part toward the extreme right and left, while those which are normatively modal as regards the presence of leucite (represented by colored circles) occupy in general an intermediate position. Thus the rocks with leucite in the norm but not in the mode, and therefore abnormative in this respect, (represented by uncolored circles), are found, with few exceptions, well to the right or toward the low silica side of the diagram. On the other hand, the rocks with leucite in the mode but not in the norm (represented by colored squares) are almost all well toward the left or toward the side of high silica, and those free from either normative or modal leucite still more to the left.

A further fact which is to be noted is that none of the rocks with abnormatively modal leucite fall inside the quartz-orthoclase-albite area OAQ, in this conforming to the conclusion reached above, that leucite is not formed from magmas with an excess of silica or normative quartz.

Advancing more into details in our comparison, we must determine whether the rocks with leucite in the norm, or in the mode, or in both,

fall within the leucitic areas corresponding to their content in molecules of anorthite and femic minerals. This is the crucial test of the validity of our assumed order of affinity for silica; for it follows from the preceding discussion that for any given set of magmas containing a definite amount of anorthite and femic molecules in the norm (however these may be crystallized in the mode), but with varying amounts of silica and potash the loci of normatively leucitic rocks (which should also be modally leucitic) derived from them should fall within the corresponding leucitic area; and those free from normative leucite (which should also be free from this in the mode) should fall outside of this, either to the right or to the left.

We have seen that the introduction of salic lime into the magma causes only a slight change in the positions of the leucite-nephelite and orthoclase-nephelite boundaries of the leucitic area, though it has a much greater effect on the leucite-orthoclase boundary above, lowering this very decidedly. The effect of the introduction of the constituents of the femic minerals, on the other hand, is much more marked and varied in its character. The leucitic area shifts somewhat to the left if pyroxene enters into the norm,[1] while with olivine, and with magnetite and other minerals free from silica, the shift is still greater and toward the right or less siliceous end. At the same time, the upper boundary is lowered to an extent even greater than is caused by salic lime. It is to be remembered, however, that, whatever the constituents thus introduced or assumed to be present, the angle *LNO* and the inclination of the leucitic area to the horizontal line QAMN do not vary, the lines *LN* and *ON* always being parallel. A few simple cases have been plotted on Plate II, but it is obvious that, for purposes of adequate comparison of actual rocks with their theoretical leucitic areas, some means must be had of determining the true position of the leucitic area corresponding to any given rock, whatever be its composition and however complex it may be as regards its mode or norm. Fortunately this determination is not difficult, nor does it involve an inordinate amount of calculation.

The method consists, in brief, of the calculation of the locus (expressed in terms of the percentages of silica and of potash) of one

[1] This shift toward higher silica would be still greater if aegirite enters into the problem, as it not infrequently does.

or more definite points of the leucitic area desired, when its size and position on the diagram can be readily laid down, the parallelism of the various lines here coming into use, and its relations to the locus of the rock can be studied. For this purpose any two of the points *L*, *O*, or *N*, may be used, but for practical purposes the simplest determination is that of the point *N*, the locus of a mixture of nephelite with the amounts of normative anorthite and femic minerals corresponding to the rock. From this the directions of the points *L* and *O* may be readily determined.

The actual process is as follows: The norm of the rock having been calculated in the usual way, the total percentage of the normative anorthite and combined femic molecules, and the total amount of silica belonging to them, are estimated. The difference between their combined percentage 100 per cent. is then assumed to be nephelite, and the amount of silica belonging to this is calculated. The sum of these percentages of silica (those of normative anorthite, femic minerals, and of nephelite) is then reduced to molecular ratio by dividing by 60, and the result is the locus *N* of the leucitic area corresponding to the rocks on the abscissal line QANM. The leucite-nephelite and orthoclase-nephelite boundaries of this area are determined by drawing lines from *N* parallel to the other *LN* and *ON* lines of the diagram, the points *L* and *O* being readily determined by calculating the amount of potash or silica corresponding to a mixture of anorthite + femic molecules and either leucite or orthoclase, respectively, in the same proportions that were used in the case of nephelite.[1]

In actual practice, however, it was found that the determination of the points *L* and *O* was seldom necessary, and the comparison between the leucitic area and the locus of the rock was accomplished without defacing the plotted diagram and very quickly, after the point *N* had been determined, by means of a square sheet of stiff paper from which a triangle had been cut, whose lower angle *LNO* and inclination as regards the lower edge of the paper corresponded to those of the plotted leucitic areas in the diagram. By placing the sharp lower apex of this triangular opening at the determined point *N*,

[1] The locus of *N* for every rock, as thus calculated, is given in the list of analyses in the Appendix.

keeping the lower edges of the sheet and of the diagram parallel, it could easily be seen if the locus of the rock fell within or without its corresponding leucitic area.[1]

It should be said that, in any such study of the relations of rocks to their theoretical areas, the data will be, of course, strictly comparable only if the analytical figures are reduced to the same condition, by eliminating water and other nonessential ingredients and by recalculating the remainder to 100 per cent. To render our comparisons strictly accurate, this should have been done for all the analyses whose loci are shown on Plate II. But this would have involved a very considerable amount of work and the expenditure of much time, which the study did not seem to warrant, especially as it was found that the changes in position thus brought about were for the most part so small as to be negligible in the scale of the diagram here given, except in the case of some manifestly altered rocks, the greater number of which have been omitted.

On examination of the diagram in this way it was found that, making due allowance when necessary for rather large amounts of water, carbon dioxide, etc., the loci of all the rocks with normative leucite fell inside their respective leucitic areas, with two exceptions, Nos. 92 and 177, which fall to the right of the area. But the norms of these show the presence of kaliophilite, there being therefore an excess of potash, so that their position is quite in accordance with our assumptions. Of the rocks without normative leucite the loci fall outside of the leucitic areas, with the exception of Nos. 104, 105, and 106, orendites and a wyomingite of the Leucite Hills. But these also have an excess of alkalies, as shown by the presence of potassium metasilicate in the norm, so that, while they should fall to the left of the line ON, being free from normative leucite, the large amount of potash raises their loci so as to make them fall inside the leucitic area. It must also be borne in mind that the rocks free from normative leucite include the vast majority of all known rocks, only a few of which are plotted in the diagram, and concerning whose locus outside the leucitic area there can be no question. We may therefore consider the proposition as established, namely, that the

[1] A square sheet of thin, transparent celluloid, properly marked, would be better than the paper.

locus of a rock will fall inside or outside its corresponding leucitic area according as it does or does not show leucite in the norm.

It will be observed that the great majority of these rocks which show both normative and modal leucite are distinctly high in potash, for the most part containing over .050 mol. prop. of K_2O, and that silica and potash both tend to increase with decrease in the amount of femic molecules, the black and the green circles lying above and to the left, and the red ones to the right and below; also the range in silica is greater with increasing potash. A study of the list of analyses will show that, with the exception of a leucite-syenite of Magnet Cove and the missourite of the Highwood Mountains, all these rocks are effusive flows.

But there are a considerable number of cases which do not conform to our assumed order and which are to be regarded as constituting exceptions to the rule, and which therefore demand an explanation. These exceptions are of two kinds—namely, rocks with normative leucite, but free from it in the mode, though falling inside their leucitic areas; and rocks with leucite developed modally, though free from it normatively, and falling outside their leucitic areas. The loci of the first kind of these exceptions, indicated by uncolored circles, fall for the most part well toward the less siliceous end of the diagram, and most of these rocks are low in potash and belong to the salfemane class. The loci of the other kind of exceptions, indicated by colored squares, fall mostly well toward the more siliceous end, the rocks are often quite high in potash, and they are pretty well distributed among the persalane, dosalane, and salfemane classes.

The cases of the first kind are exceptional, and do not conform to the assumed order of affinity, because no leucite has crystallized, though it should be present according to our theory; while the cases of the second kind are exceptional in that albite has been formed rather than nephelite, and leucite rather than orthoclase, at least in part, in these soda having an apparently greater affinity for silica than has potash.

But before considering these exceptions it will be pertinent to the discussion to assume another order of affinity, and to calculate the norms and their loci on the basis that soda has a greater affinity for silica than potash has, or, expressed mineralogically, that albite

will form rather than nephelite, and leucite rather than orthoclase, in which respect the cases of the second kind are peculiar. For this purpose we need only consider the simplest case, that of a persalic and peralkalic magma, without excess of silica and with alumina equal to the total alkalies, as formerly.

It is clear that on this assumption the line representing purely feldspathic norms, composed only of orthoclase and albite, will be identical with that calculated on the previous assumption. It will be the line O^1A^1 on Plate II (p. 270). Also the line representing purely lenic norms, composed only of leucite and nephelite, will coincide with L^1N^1. Similarly, if the magmas are perpotassic (that is, quite free from soda), the upper limiting line will coincide with the previous one $L^1O^1Q^1$.

The divergence from the previous assumption will be expressed by the line representing norms composed only of albite and leucite, along which these are in equilibrium, so that magmas with less silica for any given percentage of potash will yield norms composed of albite, nephelite, and leucite, while those with more silica will yield norms composed of orthoclase, albite, and leucite. This is the dotted black line L^1A^1 of Plate II. The orthoclase-albite-leucite area $L^1O^1A^1$ is comparatively small, and with a range in silica only from that of albite to that of leucite, while the albite-leucite-nephelite area $L^1A^1N^1$ is much larger and with a range in silica from that of albite to that of nephelite.

On this assumption, therefore, we should expect to find very many more rocks with leucite than rocks with orthoclase, and orthoclase rocks should be relatively less abundant on this assumption than should leucite rocks be on the other. Also we could expect to find leucite rocks with silica percentages up to 68.70, and the range in silica of leucitic rocks should increase with decreasing potash. It need scarcely be pointed out that the facts of petrography are directly contrary to these deductions. Furthermore, not a single leucite rock falls within the area $L^1O^1A^1$,[1] and the position of the line L^1N^1, and the shape and position of the areas $L^1O^1A^1$ and $L^1A^1N^1$, are wholly discordant with the positions of the leucitic rocks as actually observed and plotted. Similar discordances would be observed were

[1] The apparent exception seen in the diagram will be discussed later.

the affinity of other oxides for silica, as lime, magnesia, or ferrous oxide, assumed to be greater than that of potash; but these need not be discussed here.

The general coincidence between fact and theory on the first assumption, and the grave discordance observed on the second, are clear proof that the former is in general the correct one, and that, while some exceptions do exist, in the vast majority of cases potash has a greater affinity for silica than soda has. Dismissing, therefore, any other assumption as to affinity for silica than the one with which we started, we may proceed to examine the exceptional cases mentioned above. These show clearly that our assumed order of affinity, while valid in most cases, is not a constant one, but that it can be superseded by other factors, into the character of which we have now to inquire.

Considering first the rocks with normative but not modal leucite, it is found that a large proportion of them are effusive rocks containing glass, their incomplete crystallization rendering their evidence inconclusive. It will be observed, however, that the great majority of these glassy rocks, while low in silica, are relatively high in alkalies, especially soda. The list of analyses shows that they are mostly nephelinites and nephelite-basalts in common parlance, all belonging to the lenic orders, and that most of them are dosodic. Their incomplete crystallization is in accord with this relatively alkalic character, as the researches of Lagorio and others show that such alkalic magmas are prone to undercooling and the formation of glass. From what we know of the order of crystallization which generally obtains in effusive rocks, and the usually late appearance of leucite, it is highly probable that leucite would have formed, in many cases at least, had the conditions permitted complete crystallization. We may therefore reasonably eliminate these from the list of exceptions on the presumption that, had they been holocrystalline, they would have been modally leucitic and hence not exceptional.

But again we find a very considerable number of perfectly holocrystalline rocks with normative but not modal leucite, represented by uncolored circles. These, it will be observed, are apt to fall toward the lower part of the diagram; that is, they are poor in potash: and they lie for the most part well toward the right; that is, they

are low in silica. Furthermore, the greater part of them contain large amounts of femic minerals, falling in salfemane and dofemane, with a few in dosalane, and none at all in persalane. Again, it will be observed that, with some exceptions, especially of melilite-basalts, they are all intrusive bodies, which have therefore solidified under conditions very different from those of the effusive flows, as are almost all of the rocks with both normative and modal leucite.

Of these exceptional rocks some contain very considerable amounts of biotite, as Nos. 109, 140, 159, 164, and 193. These rocks are all intrusive, and the conditions of solidification were such that the potash, in combination with magnesia and ferrous oxide, and in the presence of mineralizers, formed the complex biotite molecule, instead of leucite and olivine, as would have been the case under other circumstances. It may be noted, however, that in biotite the potash controls as much or more silica than it does in leucite, and thus conforms to the assumed order of affinity. Thus, if the molecule of biotite be written as $(K,H)_2O.(Al,Fe)_2O_3.2SiO_2+n[2(Mg,Fe)O.SiO_2]$, the ratio of SiO_2 to K_2O in the salic portion is that of leucite if K : H be 1 : 1, while it is that of orthoclase if it be 1 : 2, as is usually the case. Consequently, while the physico-chemical conditions have brought about the formation of the very complex mineral biotite instead of the more simple minerals leucite and olivine, the assumed order of affinity may be considered to hold good.

Others of these exceptions, as Nos. 73, 125, 127, and 178, are rocks which consist very largely of hornblende or augite, and the norms of which contain very small amounts of leucite, only from 1 to 3 per cent. In these cases the amount of potash present is relatively so small that a great affinity for silica might be readily masked or overcome by the mass action[1] of the complex molecules of the minerals which make up most of the rock, and which would incorporate the small amount of potash in their molecules.

Some other cases are of ijolites and urtites, rich in nephelite and aegirite or aegirite-augite, as Nos. 100, 101, 102, 103, 158, 170, and 171. The formation of the sodic pyroxene in these is conditioned by the excess of alkalies over alumina and the presence of ferric oxide, and as the soda in this controls twice as much silica as it does in nephe-

[1] Cf. S. L. Penfield, *American Journal of Science*, Vol. XXIII (1907), p. 25.

lite, relatively less is left for the potash. The latter enters into the modal nephelite, which, as we know, always contains considerable potash and apparently has a rather complex molecule. Nephelite is present in very large amounts in these rocks, so that its mass action, as well as that of the abundant and complex pyroxene (which often contains some potash), may reasonably be considered to come into play in capturing the potash and preventing the formation of leucite. It is highly probable, also, that the physical conditions enter in as factors, since the rocks just discussed are all intrusive, while we find some with very similar chemical characters (as Nos. 99, 162, and 163) which have solidified at or near the surface and which contain much modal leucite, in spite of their high content of soda.

There are also some melilite basalts (Nos. 146, 157, 179, 186, 187, 188, 194 ,and 195), in which glass is present either in very small amount or not at all, so that the absence of leucite from these effusive rocks cannot be ascribed to incomplete crystallization. This is to be attributed rather to the mass action of the abundant, complex melilite, which always contains some potash; to the comparative richness of these rocks in soda, and the consequent forcing of part of the potash into the abundant nephelite; and in some instances to conditions which favored the stability of biotite, as in the alnoal types (alnöites).

Let us now examine the exceptions of the other sort, those with abnormative modal leucite. These are exceptional in that, although the magma contained sufficient silica to permit the entrance of all the potash into orthoclase, as an actual fact this constituent did not take all of its theoretical quota of silica, but was content with less, forming leucite in whole or in part.

Examining the norms of these rocks, it is found that, with a few exceptions to be discussed later, they are all deficient in silica, normative nephelite and olivine being present in every case. Therefore the silica liberated through the formation of leucite instead of orthoclase by the potash could form either albite from the normative nephelite, or pyroxene from the normative olivine, or both. We find, however, that olivine is present modally in nearly all these rocks, and that they contain almost constantly abundant albite, either in soda orthoclase,or in plagioclase, or in both of these. Furthermore,

are low in silica. Furthermore, the greater part of them contain large amounts of femic minerals, falling in salfemane and dofemane, with a few in dosalane, and none at all in persalane. Again, it will be observed that, with some exceptions, especially of melilite-basalts, they are all intrusive bodies, which have therefore solidified under conditions very different from those of the effusive flows, as are almost all of the rocks with both normative and modal leucite.

Of these exceptional rocks some contain very considerable amounts of biotite, as Nos. 109, 140, 159, 164, and 193. These rocks are all intrusive, and the conditions of solidification were such that the potash, in combination with magnesia and ferrous oxide, and in the presence of mineralizers, formed the complex biotite molecule, instead of leucite and olivine, as would have been the case under other circumstances. It may be noted, however, that in biotite the potash controls as much or more silica than it does in leucite, and thus conforms to the assumed order of affinity. Thus, if the molecule of biotite be written as $(K,H)_2O.(Al,Fe)_2O_3.2SiO_2+n[2(Mg,Fe)O.SiO_2]$, the ratio of SiO_2 to K_2O in the salic portion is that of leucite if K : H be 1 : 1, while it is that of orthoclase if it be 1 : 2, as is usually the case. Consequently, while the physico-chemical conditions have brought about the formation of the very complex mineral biotite instead of the more simple minerals leucite and olivine, the assumed order of affinity may be considered to hold good.

Others of these exceptions, as Nos. 73, 125, 127, and 178, are rocks which consist very largely of hornblende or augite, and the norms of which contain very small amounts of leucite, only from 1 to 3 per cent. In these cases the amount of potash present is relatively so small that a great affinity for silica might be readily masked or overcome by the mass action[1] of the complex molecules of the minerals which make up most of the rock, and which would incorporate the small amount of potash in their molecules.

Some other cases are of ijolites and urtites, rich in nephelite and aegirite or aegirite-augite, as Nos. 100, 101, 102, 103, 158, 170, and 171. The formation of the sodic pyroxene in these is conditioned by the excess of alkalies over alumina and the presence of ferric oxide, and as the soda in this controls twice as much silica as it does in nephe-

[1] Cf. S. L. Penfield, *American Journal of Science*, Vol. XXIII (1907), p. 25.

lite, relatively less is left for the potash. The latter enters into the modal nephelite, which, as we know, always contains considerable potash and apparently has a rather complex molecule. Nephelite is present in very large amounts in these rocks, so that its mass action, as well as that of the abundant and complex pyroxene (which often contains some potash), may reasonably be considered to come into play in capturing the potash and preventing the formation of leucite. It is highly probable, also, that the physical conditions enter in as factors, since the rocks just discussed are all intrusive, while we find some with very similar chemical characters (as Nos. 99, 162, and 163) which have solidified at or near the surface and which contain much modal leucite, in spite of their high content of soda.

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my comparative study of the norms and modes of the Italian leucitic rocks[1] showed that it was more frequently the normative nephelite rather than the normative olivine which became silicated, though the latter may also take up silica. If follows then in these cases that, not only did the potash show a less affinity for silica than did the soda, at least in part, but that the soda had a greater affinity for silica than had the magnesia and ferrous oxide. This latter fact, it will be observed, is in perfect harmony with the order of affinity for silica assumed as fundamental in the calculation of the norm and mentioned above.

One more fact is to be noted in this connection—namely, that, while the amount of leucite formed varies much, even attaining the maximum possible in some cases, the silica liberated is never more than what may be completely used up in the formation of either albite or pyroxene, so that we never find an excess of it which would be crystallized as quartz. This is in accordance with the conclusion reached from the study of the diagrams, that quartz should not occur with leucite; and this applies as well to nephelite.

These exceptional cases, represented by colored squares, fall toward the left side of the diagram, extended over a rather broad oblique zone, which is approximately the space between the lines O^6N^6 and O^4N^4, only a few being to the right of this on the less siliceous side, while rather more fall to the left of O^4N^4. As regards potash they vary widely, from about .025 to .125. In connection with their distribution it must be remembered that, were all known rock analyses plotted, this space would also contain a much greater number of uncolored squares, representing rocks free from both normative and modal leucite, only a few of which are presented here.

This zone, occupied by rocks which are normatively free from leucite, but which may or may not carry it in the mode, is that of the magmas which have been referred to as "critical" ones, as regards the formation of leucite, this implying that they are in a nicely balanced condition chemically, so that a comparatively slight change in the

[1] *The Roman Comagmatic Region* (Carnegie Publication No. 57, 1906), pp. 155, 187. Cf. also A. Lacroix, *Comptes Rendus*, Vol. CXLI (1905), p. 1191, who shows that in some cases much of the olivine may take up silica, and so induce the formation of leucite, when the soda is so low that the entrance of all of it into albite may not do this.

physical conditions during solidification may induce or prevent the formation of leucite.

It has been noted above that the replacement of orthoclase by leucite may take place to varying degrees, and when the positions of these colored squares are compared with their respective leucitic areas, it is found that, as a general thing, the nearer they lie to these, the richer they are apt to be in leucite, and the more completely the potash has entered this mineral; while the farther away they are, the poorer the rock is in leucite. So that it may be said that the tendency to form leucite increases with the nearness of the locus of the rock to its leucitic area, or as silica and soda decrease and as potash increases, other things being the same.

Indeed, an examination of the published descriptions of the rocks which fall well to the left of and far from their leucitic areas reveals the fact that the amount of leucite in most of them is very small, and that this mineral is made prominent in the name chiefly because of its rarity, and of the desire to distinguish varieties containing it, even in small amounts, from similar rocks which are free from it. These cases would include such rocks as the leucite-banakites and shoshonites of the Yellowstone National Park, the leucite-kulaite of Phrygia, leucite-tephrites of Bohemia, and leucite-rhomben-porphyries of Kilimanjaro, and many others, into the details of which it is unnecessary to enter here.

But, even granted the accessory character of the leucite in these rocks, they still do not conform to our assumed order of affinity. There are also those rocks in which the abnormative leucite forms an essential and abundant component; and, furthermore, we have to take into consideration the fact that in the rocks with both normative and modal leucite the amount of the latter almost always exceeds that of the former, so that actually a greater amount of leucite has been formed than is demanded by theory.

In this connection it will be of interest to give a few illustrations of such relations of norm and mode, so as to show the extreme variations which are possible, and the actual divergencies in some cases. In the adjoining table are given the norms of some Italian leucitic rocks, in which the amount of modal leucite has been estimated. The columns headed "a" are calculated on the regular assump-

tion that potash, and those headed "b" on the assumption that soda, has the greater affinity for silica. The amount of leucite actually present in the rock is given in the legend below.

	I		II		III		IV	
	a	b	a	b	a	b	a	b
Or	52.26	27.52	50.04	26.69	61.72	10.56	11.20	none
Ab	17.29	28.82	15.20	26.20	0.52	24.63	none	11.00
An	8.62	8.62	12.23	12.23	9.45	9.45	13.07	13.07
Lc	none	19.40	none	18.31	none	40.11	26.60	35.32
Ne	6.25	none	5.94	none	13.06	none	12.78	6.84
Di	6.05	6.05	7.17	7.17	7.98	7.98	23.55	23.55
Ol	1.05	1.05	1.87	1.87	1.97	1.97	6.05	6.05
Mt	4.41	4.41	3.94	3.94	2.32	2.32	3.48	3.48
Il	1.06	1.06	1.37	1.37	1.52	1.52	0.76	0.76
Hm	0.80	0.80	.....	.....	.....	.....	.....	.....
Ap	0.94	0.94	0.53	0.53	0.34	0.34	1.77	1.77

I. Bagnoreal ciminose (leucite-trachyte). Bagnorea, Vulsinian District (*Rom. Com. Reg.*, p. 68). Modal leucite = 8.8 per cent.

II. Bagnoreal ciminose (leucite-trachyte). Monte Venere, Ciminian District (*Rom. Com. Reg.*, p. 69). Modal leucite = 16.9 per cent.

III. Foglianal vicose (leucite-tephrite). Monte Fogliano, Ciminian District (*Rom. Com. Reg.*, p. 93). Modal leucite = 40.6 per cent.

IV. Scalal braccianose (leucite-tephrite). La Scala, Mount Vesuvius (*Rom. Com. Reg.*, p. 120). Modal leucite = 35.6 per cent.

On comparison of the norms and modes it will be seen that in I only about half the maximum possible amount of leucite has developed, in II the maximum is nearly reached, and in III and IV the whole amount of the potash possible has gone into leucite, no orthoclase being present in the mode of the last rock.[1]

It is evident that the problem is fundamentally different from that presented by the former sort of exceptions, where the absence of leucite could be readily and reasonably explained either by incomplete crystallization or by the mass action of the abundant and complex alferric minerals and nephelite. Here, on the contrary, the majority of these abnormatively leucitic rocks contain relatively large amounts

[1] A similar comparison has been undertaken by Lacroix (*Comptes rendues*, Vol. CXLI [1905], p. 1190), in discussing the granular leucitic sommaites of Monte Somma, though his norms are not calculated in the regular way, as he makes all the soda enter albite and does not assume the normative diopside molecule with $CaSiO_3$=(Mg, Fe) SiO_3.

of potash and small amounts of alferric minerals and often of nephelite, so that the mass action of these (which would also certainly tend to prevent the formation of leucite) may be neglected. Furthermore, some of these abnormatively leucitic rocks are vitreous, so that the leucite has been formed in spite of their incomplete crystallization.

The explanation of the abnormality in the behavior of potash toward silica in these cases may be explained by two sets of factors, or rather by a combination of the two.

The tendency of the $CaAl_2Si_2O_8$ molecule to crystallize with that of $NaAlSi_3O_8$ as the mixed crystals of the soda-lime feldspars is well known. Pure anorthite is a rather rare feldspar, being met with, for the most part, only in rocks belonging to docalcic and percalcic rangs, gabbros and some basalts, though it occurs in a few rocks, andesites, vulsinites,and ciminites, which are decidedly alkalic. But, speaking generally, the affinity of lime (in anorthite) for soda (in albite) seems to be very strong. Likewise purely potassic orthoclase and microcline are rarely met with, these minerals nearly always carrying very notable amounts of soda, as may be seen in the analyses given in Hintze's *Mineralogie*. On the other hand, both albite and anorthite, as well as their mixed crystals, the soda-lime feldspars, contain very little potash, the amount of this constituent in the analysis of the soda-lime feldspars being usually very small, and generally far less than the amounts of soda in orthoclase and microcline.

It is reasonable, therefore, to suppose that, under certain conditions, the affinity of lime and potash for soda to form feldspars may supersede the usually superior affinity of potash for silica, with the result that the $CaAl_2Si_2O_8$ molecules in the magma, and to a less extent those of $KAlSi_3O_8$, will capture a certain amount of the soda present, forming soda-lime feldspar and soda-orthoclase. This soda will therefore bind three times as much silica as it would do if it entered into nephelite, leaving a correspondingly less quantity of this available for the potash, which would necessarily form leucite, if the amount of silica left available for it were less than enough to form only orthoclase.

Confining our attention for the moment to the soda-lime feldspars, it is evident that, on this hypothesis of the superior affinity of lime for soda, the abnormative formation of leucite would be aided by

the actual withdrawal of the amount of silica entering the albite molecule from the possibility of chemical combination with potash, that is, by the early crystallization of the sodic feldspars, at least in great part, thus bringing about the formation of leucite at a later stage. Such a withdrawal of silica by soda is rendered possible by the fact that labradorite has a greater tendency toward crystallization than have orthoclase and leucite,[1] as shown by the general truth of Rosenbusch's order of crystallization as far as regards labradorite, orthoclase, and leucite, which immediately concern us. Specific instances of this are presented by the Italian lavas, in the mantles of orthoclase about cores of anorthite and labradorite,[2] which have also been observed elsewhere, and in the inclusions of labradorite in large leucite phenocrysts.[3]

The objection may be raised to this explanation that the more calcic members of the soda-lime feldspar series, those with more anorthite than Ab_1An_1, contain less silica than does leucite, and that, furthermore, it is precisely these more calcic members, especially labradorite, which are most apt to occur in connection with leucite, as is shown in the case of the Italian leucitic rocks. It might therefore seem to follow that the early crystallization of labradorite (Ab_1An_2), with a silica percentage of only 51.4 less than that of either leucite or orthoclase, would bring about in the remaining portion of the magma an increase of the silica percentage relative to that of potash, so that the early separation of labradorite ought to tend to prevent, rather than induce, the crystallization of leucite. Such an objection, however, leaves out of account the relations of the soda to the silica, and overlooks the fact that in entering albite molecules at an early stage of the crystallization it binds more silica than it would do if it were not thus removed and crystallized later as nephelite.

From the usually late crystallization of the alkali-feldspars it

[1] Cf. C. Doelter, *Petrogenesis* (1906), p. 136.

[2] H. S. Washington, *Journal of Geology*, Vol. IV (1896), p. 549; *The Roman Comagmatic Region* (1906), p. 30.

[3] H. S. Washington, *The Roman Comagmatic Region* (1906), pp. 34, 91. Cf. E. Hussak, *Neues Jahrbuch* (1890), Vol. I, p. 168. It may be mentioned that labradorite is not listed as an inclusion in leucite by either Rosenbusch (*Mikroskopische Physiographie*, Vol. I, second half [1905], p. 32) or Iddings (*Rock Minerals* [1906], p. 242).

would seem that the influence of the binding of silica by soda in the formation of soda-orthoclase would be felt chiefly in peralkalic rocks, or, in more calcic ones, after the formation of labradorite had ceased, at least in great part. In the latter case its influence is probably comparatively slight, though in peralkalic rocks the crystallization of the alkali-feldspar and leucite is apt to be partially synchronous, so that it would be felt more strongly in these and would very materially tend to favor the formation of leucite.

In the preceding explanation it has been assumed to be a case of relative affinities, that of potash for silica and of lime and potash for soda. But it is clear that such questions of affinity may be disregarded and the result considered merely as dependent on the relative tendency toward crystallization of the several minerals involved, especially labradorite (or other soda-lime feldspars), orthoclase, and leucite. The effect would be the same in either case in influencing the formation of leucite.

Another mineral which may enter into the problem, and which would strongly influence the formation of leucite in certain cases, is analcite. This contains twice as much silica as does nephelite, and its crystallization would abstract silica from the magma, analogously to the crystallization of albite, though not to the same extent. Analcite contains two molecules of water, so that its formation can take place only when the molten magma contains water and under peculiar physical conditions. But that its presence may explain the formation of abnormative leucite in some rocks has been clearly shown by Pirsson.[1]

The presence of alferric minerals has been disregarded as yet, since the amount of these in the exceptional rocks now under consideration is usually not very large. But a slight consideration of their characters and the relations of norm and mode will show that the influence of the early crystallization of these is also favorable to the development of leucite by abstracting from the magma an abnormative amount of silica. Considering augite alone, which is the alferric mineral most commonly met with in connection with leucite, the study of the relations of the norms and modes, as in the Italian

[1] L. V. Pirsson, *Bulletin No. 237*, U. S. Geological Survey (1905), pp. 11, 170.

rocks, shows that it is largely composed of the normative diopside. With this there enters also a smaller amount of the normative anorthite to furnish the alumina, and of normative magnetite to furnish the ferric oxide, both of which are present in the augite. To satisfy the demands of the normal augite formula, which may be stated as $m\mathrm{Ca(Mg,Fe)Si_2O_6}+n\mathrm{(Mg,Fe)(Al,Fe)_2SiO_6}$, ferrous oxide and magnesia must be supplied from normative olivine, which will take up as much silica again as it contains to form a metasilicate molecule. The ferrous oxide of the normative magnetite will also demand its equivalent of silica to conform to the augite formula. Such, at least, was the set of readjustments which were found to be demanded in the case of the Italian volcanic rocks, the augite of which had been analyzed, and it is probable that the same or a very similar set would hold good in others. It will be seen that these readjustments are in the direction of the abstraction of silica from the magma by the early crystallization of augite, so that, while they may be slight in these rocks which are persalanes or dosalanes, yet the tendency of the crystallization of augite from a magma would be to favor the later formation of leucite. The influence of the early crystallization of either hornblende or biotite would be quite analogous; but, as they seldom occur in connection with leucite, they need not be discussed.

Examining the modes of the abnormatively leucitic rocks plotted on Plate II, it will be found that the great majority of them (belonging to domalkalic or alkalicalcic rangs) carry considerable soda-lime feldspar, much of which has crystallized prior to the leucite, so far as may be gathered from the published descriptions, and as may be inferred from the usual order of crystallization. The sodic character of the alkali-feldspar is less easily demonstrable in most cases, but in the Italian rocks studied by me it was shown to be invariably decidedly sodic, ranging from $\mathrm{Or_3Ab_1}$ to $\mathrm{Or_1Ab_2}$ in the modally leucitic rocks, the composition in most cases being about $\mathrm{Or_2Ab_1}$, and from $\mathrm{Or_6Ab_1}$ to $\mathrm{Or_8Ab_9}$ in those free from leucite, the average composition being about $\mathrm{Or_2Ab_1}$. The more highly sodic character of the alkali-feldspars in the modally leucitic rocks is thus quite marked. This is perhaps best seen in the case of two arsal monzonoses. That from Poggio Cavaliere contains no modal leucite, and its alkali-feldspar has the composition $\mathrm{Or_5Ab_1}$; while that of L'Arso contains

about 2 per cent. of leucite, and its alkali-feldspar is Or_4Ab_3; both rocks being chemically closely alike.[1]

It should, of course, be possible to test this theoretical withdrawal of silica by the crystallization of soda-lime feldspar and soda-orthoclase by calculation based on the modes of actual rocks. The data necessary for this would be an exact knowledge of the order of crystallization, both qualitatively and quantitatively, and the compositions of the several modal minerals. It is clear that the former would be practically almost unattainable, owing to the difficulty of deciding the relative periods in many cases, and especially on account of the simultaneous crystallization of many of the minerals.

An attempt was made, however, on several of the Italian leucitic rocks, the modes of which have been quite exactly estimated. It was assumed that all the femic and alferric minerals, the ores, augite, and olivine, as well as all the soda-lime feldspar, had crystallized before that of the soda-orthoclase, leucite, and nephelite had begun. This, of course, may or may not be in accordance with the facts, but no definite, quantitative estimate of the relations was possible in any case. Unfortunately the composition of the alkali-feldspar was also unknown, and would have been almost impossible to determine in any case, as an analysis of the orthoclase phenocrysts would not necessarily indicate that of the more numerous groundmass feldspar laths, which cannot be separated mechanically and satisfactorily from the other constituents, owing to their small size and intimate juxtaposition.

Even though, on this basis, the calculations resolved themselves largely into working out backward the norm from the estimated mode, yet the fact that the amounts of some of the minerals, especially the leucite, had been estimated physically, and the composition of the soda-lime feldspar had been determined optically, gives them some weight. It would take up too much space to give the details here, but it may be stated that the results were fully confirmatory of the view that the early crystallization of soda-lime feldspars and of soda-

[1] *The Roman Comagmatic Region* (1906), pp. 75, 77. The determination of the composition of the Arso feldspar here, based partly on Rosiwal estimates of the amounts of leucite, augite, and olivine, and partly by readjustments of the other constituents, agrees well with that determined chemically by Fuchs (*T. M. P. M.* [1872], p. 233), who gives figures yielding $Or_{10}Ab_7$. The Poggio Cavaliere feldspar has not yet been analyzed.

orthoclase diminish the silica in the magma relatively to potash, and hence favor the crystallization of leucite. This was found to be true of soda-lime feldspar alone, as the portion of the magma remaining after the abstraction of the constituents of the minerals mentioned above, and neglecting the presence of albite in the alkali-feldspar, always yielded a greater amount of normative nephelite than that shown by the rock, thus proving that silica had been abstracted. And, naturally, the effect was still more marked if soda was assumed to go into the alkali-feldspar prior to the crystallization of leucite, the amount of this calculated from the composition of the last portion of the magma being the same as that determined in the mode, even if none is present in the norm, of the rock.

It will be observed that this favorable influence of the crystallization of soda-lime feldspars on the formation of leucite, consequent on the presence of considerable salic lime in the magma, is apparently at variance with the theoretical conclusion reached previously (p. 277), and based on the relative sizes of the leucitic areas, that the presence of anorthite should tend to lessen the probability of the presence of leucite. But it must be remembered that this was based only on a consideration of ideal norms, and that the influence of anorthite in forcing the soda to take up extra silica to form the modal albite molecule was disregarded.

It may also be pointed out that this action of the anorthite molecule offers a satisfactory explanation of the fact, noted by Zirkel and mentioned above (p. 258), that leucite is more often found in combination with plagioclase than with orthoclase.

On this assumption, the tendency to the formation of abnormative leucite will increase with the potash content of the magma, since the ratio of potash to silica will increase in the last portions to crystallize, and also, especially when potash is not very high, with its richness in salic lime and in soda, since the chemical composition will then be favorable to the formation of soda-lime feldspars. In conformity with these conclusions we have already noted the fact that the loci of these abnormative rocks are apt to fall rather near their respective leucitic areas, and that they are apt to contain the more leucite the nearer they approach these—that is, the higher they are in potash. It will also be noted that those rocks in which abnorma-

tive leucite is an accessory are quite calcic, belonging to the second and third rangs.

The influence of this factor just discussed is also seen in those rocks which carry both normative and modal leucite. In all of these, with one exception, where the mode has been adequately estimated, as in the Italian lavas, the amount of modal leucite surpasses that in the norm, so that a considerable portion of it is really abnormative. The exception is the missourite,[1] in which the amount of modal leucite is less than that in the norm, the difference being attributable to the formation of some biotite under the intrusive conditions.

On a previous page (371) it was suggested that the supersession of the affinity of lime and potash for soda over that of potash for silica could take place "under certain conditions." An idea of what these conditions may be is furnished by the long-recognized fact that leucite is characteristically a mineral of effusive igneous rocks. That it sometimes occurs in intrusive bodies is now well established by occurrences in Montana, Arkansas, and Brazil. It may be noted, as bearing on the problem, that there is only one known intrusive rock, missourite, in which purely potassic and unaltered leucite is found. In the others, as the fergusite and leucite-shonkinite of Montana,[2] and the leucite-syenites and leucite-tinguaites of Brazil and Arkansas, the "leucites" are really pseudo-leucite, a mixture of alkali-feldspars and nephelite.[3]

But such occurrences of leucite are quite exceptional, and the generally recognized law may still be considered to hold good, that conditions which control during the solidification of effusive rocks favor the formation of leucite, while those obtaining in intrusive bodies tend to prevent it, the chemical composition of the magma admitting of the readjustments of silica necessary for the formation of leucite.

In this connection a few analyses will be worth quoting, which show these relations clearly. Others might be added,[4] but those

[1] L. V. Pirsson, *Bulletin No. 237*, U. S. Geological Survey (1905), pp. 118, 119.

[2] L. V. Pirsson, *op. cit.*, pp. 106, 84.

[3] Cf. Rosenbusch, *Mikroskopische Physiographie*, Vol. II, first half (1907), pp. 196, 617.

[4] A similar comparison of analyses of leucitic and non-leucitic rocks of almost identical chemical composition is given by Lacroix (*Comptes Rendus*, Vol. CXLI [1905], p. 1190).

given below demonstrate how, of two magmas of practically identical chemical composition, the one which solidifies under intrusive conditions will be free from leucite, the potash going only into orthoclase in conformity with the norm, while in effusive flows leucite is apt to be formed, the amount of orthoclase shown in the norm being diminished modally and replaced by leucite, while the amount of normative albite is increased modally. Only the amounts of the more important constituents are given here.

	I	II	III	IV	V	VI	VII
SiO_2	55.38	55.87	54.55	54.20	48.98	49.59	47.98
Al_2O_3	23.74	20.85	19.07	19.38	12.29	14.51	13.34
Fe_2O_3	0.63	2.34	2.41	3.83	2.88	3.51	4.09
FeO	1.26	1.10	3.12	2.14	5.77	5.53	4.24
MgO	0.81	0.48	1.98	1.35	9.19	6.17	7.01
CaO	0.67	3.07	3.15	2.15	9.65	9.04	9.32
Na_2O	5.29	4.81	7.67	8.01	2.22	3.52	3.51
K_2O	10.05	10.49	4.84	5.28	4.96	5.60	5.00

I. Grano-beemerose (nephelite-syenite). East Cape, Siberia. Washington, *American Journal of Science*, Vol. XIII (1902), p. 176.

II. Sabatinal beemerose (leucite-phonolite). Lake Bracciano, Italy. Washington, *Roman Comagmatic Region* (1906), p. 47.

III. Grano-laurdalose (laurdalite). Laugendal, Norway. Brögger, *Eruptivgesteine des Kristianiagebietes*, Vol. III (1899), p. 19.

IV. Phyro-laurdalose (leucite-rhombenporphyry). Kilimanjaro, East Africa, Finckh, *Rosenbusch Festschrift* (1906), p. 392.

V. Grano-shonkinose (shonkinite). Yogo Peak, Little Belt Mountains, Montana. Weed and Pirsson, *American Journal of Science*, Vol. L (1895), p. 474.

VI. Leucite-shonkinose (leucite-shonkinite). East Peak, Highwood Mountains, Montana. Pirsson, *Bulletin No. 237*, U. S. Geological Survey (1905), p. 108.

VII. Leucite-phyro-shonkinose (analcite-leucite-basalt). Highwood Peak. Highwood Mountains, Montana. Pirsson, *op. cit.* p. 168.

It may be thought that the slight differences observable in some of the constituents, especially in silica and potash, may account for the differences in the modes, at least in part. But study of the norms and the modes, so far as these latter are exactly ascertainable from the descriptions, shows indubitably that these chemical differences are entirely too slight to bring about the very great divergencies between the modes of the several pairs of rocks. The amounts of orthoclase and nephelite in the one, and of leucite and albite in the other member,

are entirely too great to be caused only by the slight variations in silica, soda, or potash shown by the analyses given above. In such magmas, therefore, whether leucite is formed or not must be held to depend upon some factor or factors extraneous to the magma itself; and these are to be looked for in the physical conditions which obtain during the solidification.

These conditions have been discussed by many petrographers, and it seems unnecessary to enlarge on them here, in view of the fact that the attitude of this paper is dominantly chemical, and because of the inadequacy of our knowledge of the physico-chemical properties of leucite, and other minerals, mentioned at the beginning of this paper (p. 259). It must suffice to say that the chief physico-chemical factors which under effusive conditions induce the formation of leucite in magmas chemically capable of permitting it seem to the writer to be:

a) The great tendency toward crystallization of the more calcic soda-lime feldspars and of leucite, that of nephelite being also considerable, but that of orthoclase being very slight under such conditions.

b) The relative stability of orthoclase, soda-lime feldspars, leucite, and nephelite, at different temperatures and pressures, the stability of the second and third of these being apparently greater under effusive conditions than those of the first and fourth. This is a matter which demands thorough experimental investigation.

c) The absence of mineralizers under effusive, and their presence under intrusive, conditions; the former permitting the magma to solidify and crystallize at a higher temperature, and so favor the formation of leucite, while the latter diminishes the viscosity, and thus permits the crystallization to proceed at a lower temperature and in a more fluid medium, which would favor the formation of orthoclase.

d) It is possible that, whether a molten magma is at rest or in motion, or whether it is subject or not to shocks, as of explosions of steam in a volcanic vent, may be of importance in inducing the crystallization of some minerals such as leucite; since it is known that tapping or agitation will frequently bring about the crystallization of an undercooled liquid.

The influence of other factors might be adduced, but the above must suffice. In any case, an appeal to them in explanation of the

formation of any mineral in igneous rocks must partake more or less of the nature of begging the question, in the absence of properly controlled physico-chemical experimental data. Any conclusions based on our present knowledge of the physico-chemical relations of minerals must rest on very insecure bases, and it were better not to attempt to draw them.

A few words may be devoted to the subsidiary point of the relative abundance of leucitic rocks. We have seen above (p. 271) that the size of the leucitic area is much smaller than those of the non-leucitic ones, the relations varying with the content in anorthite and femic molecules, but with a maximum of 21.61 per cent. of the whole in peralkalic and persalic magmas. It follows from this that the number of leucitic rocks actually to be observed should be considerably

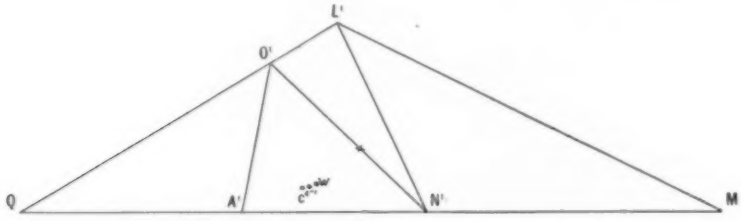

FIG. 1

less than the non-leucitic ones, though it does not follow that the actual relations must be exactly the theoretical ones. This would depend upon the general and the average compositions of all igneous rocks and the correspondence of these with the theoretical area *QLM*. As a matter of fact, we find that these do not correspond, the center of gravity of *QLM* falling at the point X (on the line O^1N^1), and the locus of the average rock well to the left of and below this, as shown in the adjoining figure. That is, igneous rocks, as they actually occur, are higher in silica and lower in potash than our theoretical magmas, of which amounts proportional to the theoretical limits of each are represented in our diagrams. It follows from this that leucitic rocks should actually be much more rarely met with than is indicated by the relative sizes of the various theoretical areas. That this is actually the case is shown by the following figures.

The normatively or modally leucitic rocks plotted in the diagram are distributed thus:

Those with normative and modal leucite	40
Those with normative but not modal leucite (vitreous)	21
Those with normative but not modal leucite (holocrystalline)	29
Those with modal but abnormative leucite	43

Reckoning the vitreous rocks with the first group, it will be seen that those which do not contain leucite when they should, and those which do contain it when they should not, pretty nearly balance each other, though the former are somewhat in the minority. They correspond, however, sufficiently well to allow the assumption for our purpose that the actual number of modally leucitic rocks corresponds with the number of those which should be leucitic according to our theory.

Now, taking the number of analyses to represent the relative amounts of the various kinds of igneous rocks, which is admittedly not strictly accurate, but sufficiently so for our purpose, and in any case being the only statistical basis we have, we find that all the analyses of igneous rocks to be found in Roth's *Tabellen* and in my *Collection*, as well as in the analyses published since and collected by me, number altogether 6,333. Of these, 278 are called leucitic, that is 4.41 per cent., while 6,055, or 95.59 per cent. are non-leucitic. While these figures are not of very great significance, on account of the unsatisfactory character of the data on which they are based, yet they are of some interest, and, taking into account the general characters and the average of igneous rocks, which would tend to lower very much the relative amounts of leucitic rocks, they are quite in harmony with our theory.

We may briefly summarize our comparison of the actual and the theoretical occurrence of leucite as follows:

The vast majority of igneous rocks conform to theory, based on the superior affinity of potash for silica, in that those whose norms are free from leucite are for the most part free from modal leucite, and the loci of nearly all of them fall outside their respective leucitic areas; while those whose norms are leucitic are very commonly modally leucitic also, and their loci all fall within their leucitic areas.

As regards modal leucite, there are certain exceptions which,

while not very numerous, are yet significant, and which may be referred to two kinds: those which are modally free from leucite, though they contain it in the norm, the abnormality being explicable, in part by the incomplete crystallization, and in part by the mass effect of the complex minerals present in abundance in these rocks, and their comparative paucity in potash; and those whose modes contain abnormative leucite, either showing none of this in the norm, or containing modally more than exists normatively, these cases being explicable by the early crystallization of soda-lime feldspars (due either to the superior affinity of lime for soda or to the great tendency toward crystallization of these feldspars), and of soda-orthoclase or analcite which may crystallize either prior to or at the same time as the leucite.

In both classes of exceptions the conditions of solidification seem to have a determining effect, those obtaining in effusive rocks favoring, and those in intrusive rocks deterring, the formation of leucite.

A few exceptions, which cannot be explained by any of the suppositions made above, remain to be discussed. The first is the so-called leucite-granite-porphyry of Brazil, described by Hussak,[1] which consists of large phenocrysts of pseudo-leucite in a fine-grained groundmass composed of orthoclase and quartz, thus apparently forming an exception to the otherwise invariable incompatibility of quartz and leucite. This highly anomalous occurrence is explained by Hussak (*loc. cit.*, *p.* 26)as the result of a "granophyric" magma breaking through a leucite-foyaite or leucite-tinguaite; and this explanation may reasonably be accepted as the true one.

The only other exceptions which need be discussed are the wyomingite and the orendites of the Leucite Hills (Nos. 104, 105, 106), which carry abundant modal leucite and whose loci fall within their leucitic area, though they do not show either leucite or nephelite in the norm, and even in one case have normative quartz. These rocks, furthermore, have an excess of alkalies over that needed for feldspar and acmite, resulting in the presence of sodium and potassium metasilicates in the norm. The peculiar features of these rocks have been discussed by Cross,[2] who shows that they cannot be due to errors of analysis,

[1] E. Hussak, *Neues Jahrbuch* (1900), Vol. I, p. 22.

[2] W. Cross, *American Journal of Science*, Vol. IV (1897), pp. 131–34.

and who leaves the discordance between their chemical and modal characters unexplained. In this condition we also are perforce compelled to leave them still, as study of the relations of norm and mode, and consideration of the presence of the phlogopite, but add to the difficulties of explanation. These rocks may well be considered as, chemically, the most remarkable and the least susceptible of correlation of any igneous rocks so far discovered.

GENERAL CONCLUSIONS

From the above discussions and comparisons we may draw certain general conclusions, both as to the affinity of the various bases in igneous rocks for silica and as to the formation of leucite, these conclusions being stated under the two separate heads.

Affinity for silica.—The assumption with which we started, that potash has a greater affinity for silica than has any of the other oxides, is amply substantiated, and may be considered as fully established, subject to certain modifications mentioned later.

Next to potash, soda has the most affinity for silica, the affinities of magnesia and ferrous oxide being considerably less, so that normative nephelite will take up silica before normative olivine.

While these relative affinities apply in the great majority of cases, and under most conditions, yet, in accordance with the general laws of chemical affinity and of mass action, they are susceptible of notable change under certain conditions, especially of temperature and pressure, and the presence of mineralizers, and may be in part superseded by the influence of the mass action of abundant complex molecules and the relative crystallizability of the minerals involved, the influence of the ready crystallization of soda-lime feldspars constituting the most notable case in point.

Soda and lime, as alumino-silicates, have a strong affinity for each other, as have soda and potash alumino-silicates, though to a somewhat less extent; and if lime and soda are present in sufficient amount in the magma, these affinities may supersede, at least partially, the usual greater affinity of potash for silica.

In the presence of water in the magma, and under certain conditions, the affinity of soda for silica may supersede that of potash, resulting in the formation of analcite and leucite.

These affinities must be regarded as acting in one direction only, that mentioned in the several cases above, since, were they reversed, the resulting modes would be quite incompatible in general with our observations.

Formation of leucite.—The formation of leucite is an unusual occurrence, and the number of leucitic rocks will always remain but a very small fraction of all known igneous rocks.

The formation of leucite is, in general, primarily dependent upon the chemical composition of the magma, subject, however, to the modifying influence of certain factors, such as physical conditions and the mass action of complex mineral molecules, to be mentioned later.

The chief chemical factors involved are the percentages of silica and of potash, and the ratio of soda to potash, but this last and the amounts of the other constituents are of subordinate importance. These statements are subject to the modifications mentioned in the preceding paragraph.

Leucite will not be formed in rocks with an excess of silica—that is, more than enough to saturate the bases completely and form the most highly silicated mineral molecules possible. It follows from this that leucite and quartz are incompatible and will not occur together.

As regards silica, rocks containing leucite may range between the silica percentage of orthoclase (64.75) as a maximum, down to the absence of silica as a minimum limiting value. The actual possible maximum will, however, depend upon the amount of anorthite and of femic molecules, all of these decreasing very markedly the possible amount of silica.

As regards potash, the limits lie between the percentage of leucite (21.56) as a maximum (though this may be conceivably exceeded owing to the existence of the kaliophilite molecule) and the disappearance of potash as a minimum. The actual maximum will depend upon the amounts of anorthite and of femic molecules present, as in the preceding case.

The greatest range in silica consistent with the formation of leucite, and consequently the greatest probability of its formation, for any given percentage of anorthite and femic molecules, will be found when the

percentage of potash is that of a mixture of orthoclase with the given amount of the other constituents mentioned. From this most favorable maximum the range in silica, and consequently the probability of the formation of leucite, will diminish rather slowly with decreasing potash, while, at the same time, the probability of the rock being non-leucitic, as well as the possible number of rocks, will increase. On the other hand, only leucitic rocks can be expected with higher potash than this amount, but their range in silica and the probability of their occurrence will diminish rapidly with increasing potash.

Similarly, the greatest range in potash, and hence the greatest probability of the formation of leucite, will be found when the silica percentage is that of a mixture of leucite with the given amount of anorthite and femic molecules. From this most favorable maximum, the range in potash and the probability of the formation of leucite will diminish slowly as silica decreases, but more rapidly as silica increases.

While the maximum ranges of silica and of potash, expressed in percentages of the whole rock are about the same (for example, 12.54 and 12.00 respectively in peralkalic persalanes), yet relatively to the amounts of each present the possible range of potash is much greater than that of silica. So that we may expect to find the potash range of leucitic rocks very great, while that of silica will be comparatively small.

If leucite is present in the norm of a rock, it should also be present in the mode, provided that the crystallization is complete and the magma has solidified under effusive conditions. The formation of leucite in such normatively leucitic magmas may, however, be, and often is, wholly prevented by the presence of femic constituents in large amounts, giving rise to the modal presence of alferric minerals with highly complex constituents, such as biotite, hornblende, augite, or melilite, the potash being incorporated in these by their mass action. The presence of abundant soda may also prevent the formation of leucite by the incorporation of the potash in the complex nephelite molecule. Both of these effects are most apt to occur if the rock has solidified under intrusive conditions. Leucite should therefore be rarely met with in highly femic rocks, as the dofemanes and perfemanes, as well as in those which are highly sodic, both of these characters implying, of course, that the magma is not very potassic.

If leucite is not present in the norm, we should not expect to find it in the mode, especially if the rock is intrusive. But if the magma has solidified under effusive conditions, is rather low in silica and high in potash, and if it contains considerable salic lime and soda, leucite is apt to form. The crystallization of soda-lime feldspar, and less often of soda-orthoclase or analcite, is a prerequisite to the formation of leucite in such cases, and the tendency to its formation will be the greater the higher the rock is in potash, though the presence of considerable salic lime and soda may bring about the crystallization of leucite even if the amount of potash is small. It follows from this that soda-lime feldspars will be frequent concomitants of leucite; and this we find to be actually the case.

The presence in the norm of such mineral molecules as nephelite or olivine, which are not fully silicated, is a necessary condition for the formation of modal leucite, if there is none in the norm; that is, the magma must be deficient in silica. Of these minerals, nephelite is the most important, modal leucite being usually formed by a readjustment of silica involving the taking-up of silica by normative nephelite to form modal albite, which usually enters the soda-lime feldspars. Olivine is much less prone to take silica away from potash, but may do so. The crystallization of alferric minerals, especially augite, also favors the formation of leucite by abstracting silica from the magma.

Effusive conditions tend to favor, and intrusive conditions tend to check or wholly prevent, the formation of leucite in magmas from which it is chemically possible for it to form. It is because of this that augite occurs more often with leucite than do hornblende or biotite. In general, the leucitoid mineral formed under intrusive conditions is the so-called pseudo-leucite, which contains a very considerable amount of soda, and which consists of an intimate mixture of orthoclase and nephelite.

Miscellaneous conclusions.—The preceding discussions emphasize the possibility of the formation of widely diverse modes from chemically identical magmas, these divergencies of the mode from the norm or from each other taking place in different directions and to varying degrees, from practically complete agreement with the norm to the greatest possible divergence from it, though these last are less

common than cases where the norm and mode correspond in many particulars.

The readjustments shown to be possible in the case of the leucitic rocks indicate that the mineral molecules probably do not exist as such in the molten magma, but that they are dissociated into simpler molecular groupings, or their constituent oxides or ions, capable of reacting differently among themselves according to the conditions of solidification.

The facts brought out in the preceding discussion do not seem to favor the theory of eutectic mixtures in explaining the crystallization of rocks, at least so far as the leucitic rocks are concerned.

There is indicated the possibility that pseudo-leucite is not a pseudomorph after original leucite, but that it replaces a distinct, soda-potash mineral, as yet unknown, which was not stable under the conditions following its period of crystallization. The evidence in regard to this will be discussed subsequently, in connection with some Sardinian leucitic lavas.

APPENDIX II

List of Rocks Plotted

No.	Symbol	SiO_2	K_2O	N	Norm and Mode	Name	Locality	Reference	Remarks
1	I.5.1.3	1.031	.071	.681	NoMo	Trachyte	Ischia	R.C.R. 20	Effusive
2	I.5.1.3	.997	.076	.673	NoMo	Trachyte	Mte. Cuma	R.C.R. 23	Effusive
3	I.5.1.3	1.006	.078	.696	NoMo	Trachyte	Mte. Nuovo	R.C.R. 23	Effusive
4	I.5.1.3	.987	.097	.672	NoMo	Trachyte	Mte. Vico	R.C.R. 23	Effusive
5	I.5.1.3	1.027	.081	.678	NoMo	Trachyte-obsidian	Ischia	R.C.R. 28	Effusive
6	I.5.2.2	.968	.095	.674	NoMo	Vulsinite	Bolsena	R.C.R. 31	Effusive
7	I.5.2.2	.960	.093	.675	NoMo	Vulsinite	Astroni	R.C.R. 31	Effusive
8	I.5.2.2	.958	.089	.671	NoMo	Vulsinite	Astroni	R.C.R 31	Effusive
9	I.5.2.2	.936	.112	.674	NoMl	Leucite-trachyte	Mte. Vico	R.C.R 36	Effusive
10	I.5.2.2	.920	.102	.665	NoMl	Leucite-trachyte	Mte. Vico	R.C.R. 36	Effusive
11	I.5.2.2	.104	.094	.711	NoMl	Leucite-granite-porphyry	Brazil	W. T. 199	Mixture of rocks
12	I.5.2.3	.960	.093	.686	NoMo	Vulsinite	Astroni	R.C.R. 43	Effusive
13	I.5.2.3	.918	.093	.676	NoMl	Leucite-trachyte	Proceno	R.C.R. 43	Effusive
14	I.5.3.2	.989	.074	.716	NoMo	Augite-syenite	British Guiana	W.T. 205	Intrusive
15	I.6.1.3	.931	.112	.687	NoMl	Leucite-phonolite	Bracciano	R.C.R. 47	Effusive
16	I.6.1.3	.893	.101	.683	NoMo	Nephelite-syenite	Beemerville	W.T. 207	Intrusive
17	I.6.1.3	.923	.107	.656	NoMo	Nephelite-syenite	Siberia	A.J.S., XIII, 1902, 176	Intrusive
18	I.6.1.3	.982	.117	.690	NoMo	Leucite-tinguaite-vitrophyre	Portugal	W.T. 207	Vitreous; no leucite
19	I.6.1.3	.920	.089	.676	NoMl	Leucite-phonolite	Eifel	W.T. 207	Effusive
20	I.6.1.4	.891	.064	.701	NoMl	Leucite-phonolite	Eifel	W.T. 211	Effusive
21	I.6.2.4	.904	.043	.660	NoMl	Leucite (?) microsyenite	Madagascar	M.M. 205	Leucite doubtful; intrusive
22	I.7.1.3	.838	.120	.691	NlMl	Leucite-tephrite	Tavolato	R.C.R. 51	Effusive
23	I.7.1.3	.892	.094	.695	NoMo	Nephelite-syenite	Magnet Cove	W.T. 215	Intrusive
24	II.4.3.3	.990	.056	.671	NoMo	Biotite-latite	Mte. Cimino	R.C.R. 56	Normative quartz
25	II.5.1.2	.931	.099	.634	NoMo	Syenite	New So. Wales		Intrusive

APPENDIX II—*Continued*

No.	Symbol	SiO_2	K_2O	N	Norm and Mode	Name	Locality	Reference	Remarks
26	II.5.1.2	.967	.107	.698	NoMo	Tinguaite	Highwood Mts.	Bull. 237, 128	Intrusive
27	II.5.2.2	.955	.097	.683	NoMo	Vulsinite	Mte. Vico	R.C.R. 59	Effusive
28	II.5.2.2	.924	.071	.709	NoMo	Ciminite	Mte. Cimino	R.C.R. 63	Effusive
29	II.5.2.2	.955	.068	.742	NoMo	Ciminite	Mte. Cimino	R.C.R. 63	Effusive
30	II.5.2.2	.931	.094	.669	NoMl	Leucite-trachyte	Bagnorea	R.C.R. 67	Effusive
31	II.5.2.2	.920	.090	.678	NoMl	Leucite-trachyte	Mte. Vico	R.C.R. 67	Effusive
32	II.5.2.2	.869	.077	.700	NoMl	Leucite-tephrite	Mte. Vico	R.C.R. 72	Effusive
33	II.5.2.2	.851	.077	.647	NoMo	Durbachite	Durbach	W.T. 255	Intrusive; biotite
34	II.5.2.2	.940	.083	.722	NoMo	Selagite	Mte. Catini	W.T. 255	Effusive; biotite
35	II.5.2.3	.920	.081	.690	NoMo	Vulsinite	Mte. Vico	R.C.R. 75	Effusive
36	II.5.2.3	.946	.063	.682	NoMl	Vulsinite	Ischia	R.C.R. 75	Effusive
37	II.5.2.3	.912	.073	.683	NoMl	Vulsinite	Astroni	R.C.R. 75	Effusive
38	II.5.2.5	.740	.008	.563	NoMl	Leucite-basanite	Mte. Ferru	Unpublished	Effusive
39	II.5.3.2	.873	.080	.661	NoMl	Leucite-tephrite	Mte. Vico	R.C.R. 80	Effusive
40	II.5.3.2	.848	.077	.672	NoMl	Leucite-trachyte	Rocca Monfina	R.C.R. 83	Effusive
41	II.5.3.2	.854	.070	.695	NoMl	Leucite-tephrite	Toscanella	R.C.R. 86	Effusive
42	II.5.3.2	.847	.074	.672	NoMo	Minette	Plauen	W.T. 265	Intrusive; biotite
43	II.5.3.2	.837	.092	.683	NoMl	Sommaite	Mte. Somma	C.R. CXLI, 1190	Intrusive (?)
44	II.5.3.3	.928	.047	.724	NoMo	Biotite-latite.	Rocca Monfina	R.C.R. 88	Effusive; normative quartz
45	II.5.3.3	.882	.051	.659	NoMl	Leucite-banakite	Yell. Nat. Park	W.T. 267	Effusive
46	II.5.3.3	.875	.039	.674	NoMl	Leucite-shoshonite	Yell. Nat. Park	W.T. 267	Effusive; leucite doubtful
47	II.5.3.3	.859	.044	.642	NoMl	Leucite-banakite	Yell. Nat. Park	W.T. 267	Effusive
48	II.5.3.3	.829	.033	.666	NoMl	Leucite-tephrite	Bohemia	W.T. 271	Effusive
49	II.5.3.3	.861	.052	.671	NoMl	Sommaite	Mte. Somma	C.R. CLXI, 1190	Intrusive (?)
50	II.5.3.3	.835	.045	.678	NoMl	Sommaite	Mte. Somma	C.R. CLXI, 1190	Intrusive (?)
51	II.5.3.4	.872	.029	.675	NoMl	Leucite-tephrite	Bohemia	W.T. 283	Effusive
52	II.6.1.1	.909	.114	.804	NlMl	Wyomingite	Leucite Hills	W.R.T. 51	Effusive
53	II.6.1.2	.863	.081	.701	NoMl	Fergusite	Highwood Mts.	Bull. 237, 86	Intrusive; pseudo-leucite
54	II.6.1.3	.885	.089	.698	NoMo	Foyaite	Magnet Cove	W.T. 293	Intrusive
55	II.6.1.3	.882	.084	.682	NoMl	Leucite-tinguaite	Magnet Cove	W.T. 293	Intrusive; pseudo-leucite
56	II.6.1.3	.961	.098	.724	NoMo	Tinguaite	Judith Mts.	W.T. 293	Intrusive

APPENDIX II—*Continued*

No.	Symbol	SiO_2	K_2O	N	Norm and Mode	Name	Locality	Reference	Remarks
57	II.6.1.3	.958	.100	.738	NoMo	Tinguaite	Bearpaw Mts.	W.T. 295	Intrusive
58	II.6.1.3	.866	.082	.686	NoMo	Syenite-porphyry	Highwood Mts.	Bull. 237, 139	Intrusive
59	II.6.1.3	.934	.093	.733	NoMo	Nephelite-syenite	Brazil	W.T. 295	Intrusive
60	II.6.1.3	.919	.074	.630	NoMo	Syenite	New South Wales	P.R.S.N.S.W. XXXVII, 341	Intrusive
61	II.6.1.4	.901	.072	.701	NoMl	Leucite-tinguaite	Magnet Cove	W.T. 295	Intrusive; pseudo-leucite
62	II.6.1.4	.903	.056	.649	NoMl	Leucite-porphyry	Kilimanjaro	R.F. 392	Effusive
63	II.6.1.4	.891	.062	.662	NoMl	Leucite-porphyry	Kilimanjaro	R.F. 392	Effusive
64	II.6.2.2	.914	.111	.688	NoMl	Leucite-tephrite	Mte. Vico	R.C.R. 92	Effusive
65	II.6.2.2	.853	.113	.670	NlMl	Leucite-tephrite	Rocca Monfina	R.C.R. 92	Effusive
66	II.6.2.2	.845	.100	.675	NlMl	Leucite-tephrite	Bracciano	R.C.R 97	Effusive
67	II.6.2.2	.839	.100	.676	NlMl	Leucite-tephrite	Bracciano	R.C.R. 97	Effusive
68	II.6.2.2	.838	.080	.680	NlMl	Leucite-tephrite	Orvieto	R.C.R. 101	Effusive
69	II.6.2.3	.856	.071	.679	NoMo	Nephelite-felsite	Magnet Cove	W.T. 297	Intrusive
70	II.6.2.3	.828	.053	.684	NoMo	Covite	Magnet Cove	W. T. 297	Intrusive
71	II.6.2.3	.868	.065	.716	NoMo	Syenite	Highwood Mts.	Bull. 237, 92	Intrusive
72	II.6.2.3	.835	.080	.660	NoMo	Syenite	Highwood Mts.	Bull. 237, 96	Intrusive
73	II.6.2.3	.833	.091	.651	NlMo	Syenite	Highwood Mts.	Bull. 237, 92	Intrusive
74	II.6.2.4	.832	.040	.704	NoMl	Leucite-kulaite	Kula	W.T. 299	Effusive
75	II.6.2.4	.806	.042	.685	NoMo	Kulaite	Kula	W.T. 299	Effusive
76	II.6.2.5	.748	.008	.610	NoMl	Leucite-basanite	Mte. Ferru	Unpublished	Effusive
77	II.6.3.2	.821	.056	.702	NoMl	Leucite-basalt	Ernici	W.T. 301	Effusive
78	II.7.1.3	.866	.104	.725	NlMl	Leucite-tinguaite	Bearpaw Mts.	W.T. 303	Intrusive; pseudo-leucite
79	II.7.1.3	.885	.073	.736	NoMo	Tinguaite	Brazil	W.T. 303	Intrusive
80	II.7.1.3	.869	.086	.711	NlMl	Leucitophyre	Brazil	W.T. 303	Effusive
81	II.7.1.3	.833	.088	.681	NlMl	Leucite-tinguaite	Beemerville		Intrusive;pseudo-leucite(?)
82	II.7.2.2	.794	.080	.721	NlMl	Leucite-tephrite	Vesuvius	R.C.R. 104	Effusive
83	II.7.2.2	.798	.087	.684	NlMl	Leucitite	Bracciano	R.C.R. 109	Effusive
84	II.7.2.2	.787	.081	.698	NlMl	Leucitite	Alban Hills	R.C.R. 113	Effusive
85	II.7.2.2	.802	.084	.672	NlMl	Leucite-tephrite	Vesuvius	R.C.R. 116	Effusive; vitreous
86	II.7.2.2	.795	.081	.702	NlMl	Leucite-tephrite	Vesuvius	R.C.R .118	Effusive

APPENDIX II—*Continued*

No.	Symbol	SiO_2	K_2O	N	Norm and Mode	Name	Locality	Reference	Remarks
87	II.7.2.2	.817	.096	.693	NlMl	Leucite-tephrite	Vesuvius	W.T. 305	Effusive
88	II.7.2.4	.708	.049	.669	NlMl	Hauynophyre	Mte. Vulture	W.T. 305	Effusive
89	II.7.3.2	.811	.069	.643	NlMl	Leucitophyre	Vesuvius	W.R.T. 53	Effusive
90	II.7.3.3	.790	.063	.716	NlMl	Leucite-tephrite	Rocca Monfina	W.T. 305	Effusive
91	II.7.3.3	.786	.070	.697	NlMl	Leucitophyre	Vesuvius	W.R.T. 53	Effusive
92	II.7.3.4	.651	.019	.652	NlMo	Nephelinite	Rhöngebirge	W.T. 305	Effusive; vitreous
93	II.7.3.4	.651	.027	.630	NlMo	Nephelite-basalt	Rhöngebirge	W.T. 305	Effusive; vitreous
94	II.8.1.4	.804	.062	.741	NlMo	Nephelinite	Odenwald	W.R.T. 53	Effusive; vitreous
95	II.8.2.4	.635	.023	.615	NlMo	Biotite-ijolite	Magnet Cove	W.T. 307	Intrusive; biotite
96	II.8.2.4	.659	.060	.600	NlMl	Hauynophyre	Mte. Vulture	Unpublished	Effusive
97	II.9.1.3	.740	.087	.664	NlMl	Leucite-syenite	Magnet Cove	W.T. 307	Intrusive; pseudo-leucite
98	II.9.1.3	.761	.074	.690	NlMo	Nephelite-porphyry	Kola	W.T. 307	Intrusive
99	II.9.1.3	.775	.072	.697	NlMl	Leucitite	Kamerun	W.T. 307	Effusive
100	II.9.1.4	.758	.045	.731	NlMo	Urtite	Kola	W.T. 307	Intrusive
101	II.9.1.4	.757	.036	.719	NlMo	Urtite	Kola	W.T. 307	Intrusiye
102	II.9.1.4	.755	.037	.728	NlMo	Urtite	Kola	W.T. 307	Intrusive
103	II.9.1.4	.717	.032	.699	NlMo	Ijolite	Kola	W.T. 307	Intrusive
104	III.5.1.1	.903	.126	.686	NoMl	Orendite	Leucite Hills	W.T. 313	Effusive; biotite
105	III.5.1.1	.901	.125	.671	NoMl	Orendite	Leucite Hills	W.T. 313	Effusive; normative quartz
106	III.5.1.1	.893	.119	.661	NoMl	Wyomingite	Leucite Hills	W.T. 313	Effusive; biotite
107	III.5.1.1	.846	.079	.659	NoMl	Jumillite	Murcia	R.F. 290	Effusive
108	III.5.1.2	.814	.061	.517	NoMl	Jumillite	Murcia	R.F. 290	Effusive
109	III.5.2.2	.840	.080	.672	NoMo	Syenitic-lamprophyre	Colorado	J.G. XIV, 168	Intrusive
110	III.5.2.2	.871	.064	.681	NoMo	Syenite-porphyry	Maine	J.G. XIV, 179	Intrusive
111	III.5.2.3	.789	.040	.683	NoMl	Leucite-absarokite	Yell. Nat. Park	W.T. 313	Effusive
112	III.5.2.4	.781	.028	.606	NoMl	Leucite-tephrite	Bohemia	W.T. 315	Effusive; normative quartz
113	III.5.3.4	.788	.023	.679	NoMl	Leucite-absarokite	Yell. Nat. Park	W.T. 321	Effusive
114	III.6.1.1	.837	.104	.682	NlMl	Wyomingite	Leucite Hills	W.T. 339	Effusive
115	III.6.1.3	.833	.034	.708	NoMo	Shonkinite	Bearpaw Mts.	W.T. 339	Intrusive
116	III.6.2.3	.827	.060	.724	NlMl	Leucite-shonkinite	Highwood Mts.	Bull. 237, 108	Intrusive; pseudo-leucite
117	III.6.2.3	.800	.054	.675	NoMl	Leucite-basalt	Highwood Mts.	Bull. 237, 168	Effusive

APPENDIX II—*Continued*

No.	Symbol	SiO_2	K_2O	N	Norm and Mode	Name	Locality	Reference	Remarks
118	III.6.2.3	.779	.040	.692	NoMo	Shonkinite	Highwood Mts.	Bull. 237, 102	Intrusive
119	III.6.2.3	.816	.053	.692	NoMo	Shonkinite	Little Belt Mts.	W.T. 341	Intrusive
120	III.6.2.3	.828	.059	.692	NoMl	Leucitophyre	Persia	W.T. 341	Effusive
121	III.6.2.4	.731	.031	.609	NoMl	Leucite-basanite	Kaiserstuhl	W.T. 341	Effusive
122	III.6.2.4	.797	.043	.670	NoMl	Leucite-tephrite	Bohemia	W.T. 343	Effusive
123	III.6.3.2	.794	.051	.716	NlMl	Leucite-tephrite	Mte. Somma	C.R. CXLI, 1192	Effusive
124	III.6.3.3	.708	.029	.669	NlMo	Monchiquite	Castle Mts.	W.T. 343	Intrusive; glass or analcite
125	III.6.3.4	.632	.022	.601	NlMo	Hornblendite	Norway	W.T. 345	Intrusive
126	III.6.3.4	.656	.019	.633	NlMl	Leucite-monchiquite	New South Wales	R.G.S.N.S.W. VIII, 50	Effusive
127	III.6.4.3	.643	.015	.631	NlMo	Ariegite	Pyrenees	W.T. 347	Intrusive
128	III.6.4.3	.686	.017	.671	NlMl	Leucite-basalt	Vogelsberg	W.T. 347	Effusive
129	III.6.4.3	.644	.007	.636	NlMo	Limburgite	Cape Verde Is.	W.T. 347	Effusive; vitreous
130	III.7.1.3	.798	.056	.700	NlMo	Malignite	Ontario	W.T. 347	Intrusive
131	III.7.2.2	.790	.073	.714	NlMl	Leucitite	Lake Bolsena	R.C.R. 124	Effusive
132	III.7.2.3	.767	.062	.665	NlMl	Minette	Highwood Mts.	Bull. 237, 144	Intrusive; biotite
133	III.7.2.4	.665	.038	.633	NlMo	Nephelite-basalt	Löbauerberg	W.T. 349	Effusive; vitreous
134	III.7.2.4	.668	.035	.611	NlMl	Leucite-nephelinite	Kamerun	W. T. 349	Effusive
135	III.7.2.4	.666	.038	.614	NlMl	Leucite-nephelinite	Kamerun	W.T. 349	Effusive
136	III.7.2.4	.655	.016	.548	NoMo	Hauynophyre	Kamerun	W.T. 349	Effusive
137	III.7.2.4	.711	.016	.693	NlMo	Basalt	Cape Verde Is.	W.R.T. 59	Effusive
138	III.7.2.4	.671	.016	.623	NoMl	Leucite-monchiquite	New South Wales	R.G.S.N.S.W. VII, 302	Effusive
139	III.7.3.2	.748	.039	.725	NlMl	Leucite-basanite	Lake Bolsena	R.C.R 127	Effusive
140	III.7.3.2	.607	.032	.576	NlMo	Ouachitite	Hot Springs	W.T. 349	Intrusive; biotite
141	III.7.3.4	.709	.023	.680	NlMo	Monchiquite	Orkney Is.	W.T. 351	Intrusive; vitreous
142	III.7.3.4	.720	.013	.701	NlMo	Nephelite-basalt	Hesse	W.T. 351	Effusive; vitreous
143	III.7.3.4	.695	.011	.671	NlMo	Basalt	Bohemia	W.T. 351	Effusive; vitreous
144	III.7.3.4	.656	.016	.638	NlMo	Nephelite-basalt	Bohemia	W.T. 351	Effusive; vitreous
145	III.7.3.4	.656	.036	.603	NlMo	Hauynophyre	Kamerun	W.T. 351	Effusive; vitreous

APPENDIX II—*Continued*

No.	Symbol	SiO_2	K_2O	N	Norm and Mode	Name	Locality	Reference	Remarks
146	III.7.3.4	.603	.019	.593	NlMo	Melilite-basalt	Cape Colony	A.R.G.C.C.G.H. 1903, 51	Effusive; melilite
147	III.7.3.4	.676	.021	.651	NlMo	Nephelite-basalt	Rossberg	W.R.T. 59	Effusive; vitreous(?)
148	III.7.3.5	.679	.006	.672	NlMo	Nephelite-basalt	Rhöngebirge	W.T. 351	Effusive; much nephelite
149	III.8.1.2	.775	.092	.657	NlMl	Leucitite	Bearpaw Mts.	W.T. 351	Effusive
150	III.8.1.2	.753	.074	.668	NlMl	Leucite-basalt	New South Wales	R.G.S.N.S.W. VII, 302	Effusive
151	III.8.2.2	.771	.068	.716	NlMl	Leucitite	Lake Bolsena	R.C.R. 131	Effusive
152	III.8.2.2	.771	.091	.687	NlMl	Leucitite	Ernici	R.C.R. 135	Effusive
153	III.8.2.2	.784	.080	.712	NlMl	Leucitite	Ernici	R.C.R. 135	Effusive
154	III.8.2.2	.767	.096	.676	NlMl	Leucitite	Alban Hills	R.C.R. 139	Effusive
155	III.8.2.2	.768	.055	.720	NlMl	Missourite	Highwood Mts.	Bull. 237, 117	Intrusive
156	III.8.2.3	.687	.038	.650	NlMo	Nephelinite	Laacher See	W.R.T. 59	Effusive; vitreous
157	III.8.2.3	.606	.039	.564	NlMo	Melilite-basalt	Hegau	W.T. 351	Effusive; melilite
158	III.8.2.4	.696	.042	.649	NlMo	Ijolite	Magnet Cove	W.T. 353	Intrusive
159	III.8.2.4	.649	.019	.629	NlMo	Biotite-ijolite	Magnet Cove	W.T. 353	Intrusive; biotite
160	III.8.2.4	.720	.043	.662	NlMo	Theralite	Crazy Mts	W.T. 353	Intrusive
161	III.8.2.4	.711	.038	.677	NlMo	Nephelite-basanite	Hesse	W.T. 353	Effusive; vitreous
162	III.8.2.4	.669	.040	.630	NlMl	Leucitic-nephelinite	Kamerun	W.T. 353	Effusive
163	III.8.2.4	.640	.026	.607	NlMl	Leucitic-nephelinite	Kamerun	W.T. 353	Effusive
164	III.8.2.4	.661	.033	.626	NlMo	Teschenite	Cape Verde Is.	W.T. 353	Intrusive; biotite
165	III.8.2.4	.661	.033	.620	NlMo	Olivine-diabase	Cape Verde Is.	W.R.T. 59	Intrusive; vitreous(?)
166	III.8.2.5	.769	.010	.758	NlMo	Nephelinite (andesite)	Grenada	W.T. 353	Effusive; vitreous
167	III.9.1.2	.711	.085	.625	NlMo	Madupite	Leucite Hills	W.T. 353	Effusive; vitreous
168	III.9.1.4	.751	.031	.737	NlMo	Nephelinite	Odenwald	W.R.T. 61	Effusive; vitreous
169	III.9.1.4	.747	.039	.716	NlMo	Nephelinite	Odenwald	W.R.T. 61	Effusive; vitreous
170	III.9.1.4	.728	.030	.690	NlMo	Ijolite	Kola	W.T. 353	Intrusive
171	III.9.1.5	.701	.020	.684	NlMo	Ijolite	Kola	W.T. 353	Intrusive
172	IV.$1^3_2 1^2_2 1$	.701	.012	.691	NlMo	Limburgite	Habichtswald	W.T. 355	Effusive; vitreous
173	IV.$1^2_2 1^2_2 1$	.714	.007	.719	NlMo	Olivine-basalt	Grenada	W.T. 355	Effusive; vitreous
174	IV.$1^3_2 1^2_2 1$	.789	.028	.695	NoMl	Jumillite	Murcia	R.F. 305	Effusive

APPENDIX II—*Continued.*

No.	Symbol	SiO_2	K_2O	N	Norm and Mode	Name	Locality	Reference	Remarks
175	IV.$1^4_1 2^3$	.672	.012	.673	NlMo	Nephelite-basalt	Rhöngebirge	W.T. 357	Effusive; vitreous (?)
176	IV.$1^5_1 1^2$	.654	.006	.648	NlMo	Hornblende-peridotite	Pyrenees	W.T. 357	Intrusive
177	IV.$1^5_1 3^2$	.691	.079	.711	NlMl	Venanzite	Umbria	W.T. 357	Effusive
178	IV.$2^1_1 3^2$	.751	.009	.746	NlMo	Pyroxenite	Norway	W.T. 359	Intrusive
179	IV.$2^2_1 1^2$	.637	.024	.606	NlMo	Melilite-basalt	Hegau	W.T. 359	Effusive
180	IV.$2^2_1 2^2$	.635	.014	.622	NlMo	Nephelite-basalt	Rhöngebirge	W.T. 359	Effusive; vitreous (?)
181	IV.$2^2_1 1^2$	.665	.020	.659	NlMo	Nephelite-basalt	Löbauerberg	W.T. 359	Effusive; vitreous (?)
182	IV.$2^2_1 1^2$	.726	.064	.636	NlMl	Leucite-basalt	New South Wales	R.G.S.N.S.W., VII, 302	Effusive
183	IV.$2^2_1 1^2$	.640	.008	.640	NlMo	Jacupirangite	Magnet Cove	W.T. 361	Intrusive
184	IV.$2^3_1 1^2$	.672	.012	.653	NlMo	Nephelite-basalt	Texas	W.T. 361	Effusive; vitreous (?)
185	IV.$2^3_1 1^2$	.665	.011	.650	NlMo	Nephelite-basalt	Texas	W.T. 361	Effusive; vitreous (?)
186	IV.$2^3_1 1^2$	.648	.017	.640	NlMo	Melilite-basalt	Hegau	W.T. 361	Intrusive
187	IV.$2^3_1 1^2$	.609	.017	.591	NlMo	Melilite-basalt	Hegau	W.T. 361	Effusive
188	IV.$2^3_1 2^2$	.633	.021	.625	NlMo	Melilite-basalt	Westphalia	W.T. 363	Effusive
189	IV.$2^3_1 1^2$	.658	.020	.636	NlMo	Nephelite basalt	Löbauerberg	W.T. 363	Effusive; vitreous
190	IV.$2^3_1 1^2$	.660	.008	.659	NlMo	Nephelite-basalt	Silesia	W.R.T. 61	Effusive
191	IV.$2^4_1 2^2$	.633	.007	.628	NlMo	Melilite-basalt	Texas	W.T. 363	Effusive
192	IV.$2^4_1 1^2$	.653	.016	.629	NlMo	Nephelite-basalt	Hesse-Cassel	W.T. 363	Effusive
193	IV.$2^5_1 1^3$	.583	.058	.500	NlMo	Biotite-peridotite	Harz Mts.	W.T. 365	Intrusive
194	IV.$3^2_1 1^2$	.597	.016	.578	NlMo	Melilite-basalt	Hegau	W.T. 365	Effusive
195	IV.$3^4_1 1^2$	.593	.019	.568	NlMo	Melilite-basalt	Hegau	W.T. 365	Effusive

ABBREVIATIONS

A.J.S=	*American Journal of Science* (New Haven)
A.R.G.C.C.G.H.=	*Annual Report of the Geological Commission of the Cape of Good Hope.*
Bull. 237=	Pirsson, "Igneous Rocks of the Highwood Mountains, Montana," *Bulletin No. 237*, U. S. Geological Survey (1905).
C.R.=	*Comptes Rendus de l'Academie des Sciences* (Paris).
J.G.=	*Journal of Geology* (Chicago).
R.C.R.=	Washington, *The Roman Comagmatic Region*, Carnegie Publication No. 57 (1906).
R.F.=	*Rosenbusch Festschrift* (Stuttgart, 1906).
R.G.S.N.S.W.=	*Records of the Geological Survey of New South Wales.*
W.R.T.=	Roth's *Tabellen*, arranged by Washington. *Professional Paper No. 28*, U. S. Geological Survey (1904).
W.T.=	Washington's *Tables*, 1884–1900. *Professional Paper No. 14*, U. S. Geological Survey (1903).
Nl=	leucite present in the norm.
No=	leucite not present in the norm.
Ml=	leucite present in the mode.
Mo=	leucite not present in the mode.

STUDIES FOR STUDENTS[1]

THE RECENT ADVANCE IN SEISMOLOGY

WILLIAM HERBERT HOBBS
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II. THE CO-ORDINATED "DISTANT" STUDY OF EARTHQUAKES

As already stated, in the first of these papers,[2] the one to whom we owe most for the exploitation of this new field for seismological study is Professor John Milne, whose later achievements crown a lifetime devoted to geophysical researches.[3] In 1883 he wrote: "It is not unlikely that every large earthquake might with proper appliances be recorded at any point on the land surface of the globe." Six years later the late von Rebeur-Paschwitz detected, in the photographic records of a very delicate horizontal pendulum, movements which he traced to earthquakes at a very great distance. These studies, published in 1895,[4] were thus the first to verify the prophetic

[1] Owing to the rapid development of the New Seismology, few treatises upon the subject have appeared. In addition to the briefer statements in Milne's *Seismology* (London, 1898) and Dutton's *Earthquakes* (London and New York, 1904), the student may with profit consult *Handbuch der Erdbebenkunde* by A. Sieberg, secretary of the German Chief Station for Earthquake Study at Strassburg. The subject will be more elaborately treated in Sieberg's *Geophysik*, soon to appear, and in *La science séismologique* by Count de Montessus de Ballore, which it is expected will also be issued during the present season. The most satisfactory treatment of the more strictly geological side of the subject of earthquakes is to be found in *Erdbebenkunde, die Methoden ihrer Beobachtung*, by Rudolph Hoernes (Leipzig, 1893).

[2] *Journal of Geology*, Vol. XV, pp. 288–97.

[3] John Milne, "Seismological Observations and Earth Physics," *Geographical Journal*, London, Vol. XXI (1903), pp. 1–25, map.

[4] E. von Rebeur-Paschwitz, "Europäische Beobachtungen des grossen japanischen Erdbebens vom 22. März 1894, und des venezuelanischen Erdbebens vom 28. April 1894, nebst Untersuchungen über die Fortpflanzungsgeschwindigkeit dieser Erdbeben," *Petermann's Mitteilungen*, Vol. XLI (1895), pp. 13–21, 39–42. (See also *Beiträge zur Geophysik*, Vol. II.)

words of Milne uttered twelve years earlier.[1] Today seismologists have so perfected recording instruments that at all first-class stations they are able to report great earthquakes which have occurred anywhere upon the globe, and less than a half-hour after their occurrence, the news having been telegraphed to them by the earth itself through, it may be, its entire diameter; and to have their reports confirmed by the telegraphic cables some hours or days later, according as cables have or have not been fractured. In his observing-station at Shide, upon the Isle of Wight, Professor Milne has been able to reassure anxious friends after the press announcement of a terrible earthquake in a nearly antipodal region, and confirm the fact from later press dispatches that the earlier report was a fabrication.[2]

The possibility of fixing the location of the disturbed region in the case of one of these so-called "unfelt quakes" is inherent in the fact that the waves of macroseisms are transmitted apparently not only through the mass of the globe, but also along its circumference. Those waves which first reach the station, the "preliminary tremors" of the seismogram (see Fig. 1), appear to come by the direct route through the earth's mass, as is pretty clearly shown by their constancy of velocity when the station is distant, and their variability of speed when the disturbed district is near. For the long distances the velocity is quite uniform and about 10 kilometers per second, so that the diameter of the earth is traversed in about 20 minutes.

The Japanese school of seismologists have generally held that the waves which produce these preliminary tremors in the seismogram

[1] An excellent account of the growth of the new methods of study may be found in the paper by W. Schlüter, "Schwingungsart und Weg der Erdbebenwellen," *Beiträge zur Geophysik*, Vol. V (1901), pp. 314–59.

[2] For a description of modern seismographs see C. E. Dutton, *Earthquakes in the Light of the New Seismology* (London and New York, 1904), in which the Italian instruments designed by Agemennone are described with especial fulness; C. F. Marvin, "The Omori Seismograph at the Weather Bureau" (*Monthly Weather Review*, June, 1903, pp. 1–8) and "Improvements in Seismographs with Mechanical Registration" (*ibid.*, May, 1906, pp. 1–6), where the Borsch-Omori instruments with Marvin's excellent improvements are described; A. Sieberg, *Handbuch der Erdbebenkunde* (Braunschweig, 1904), where the Wiechert Astatic Seismometer, the most modern and satisfactory instrument, though the most difficult to manage, is described and figured. Much may be learned from the trade catalogues of Spindler & Hoyer, of Göttingen, the manufacturers of the Wiechert instrument, and of J. &. A. Borsch, 15 Münstergasse, Strassburg, the European manufacturers of the Omori type of pendulum.

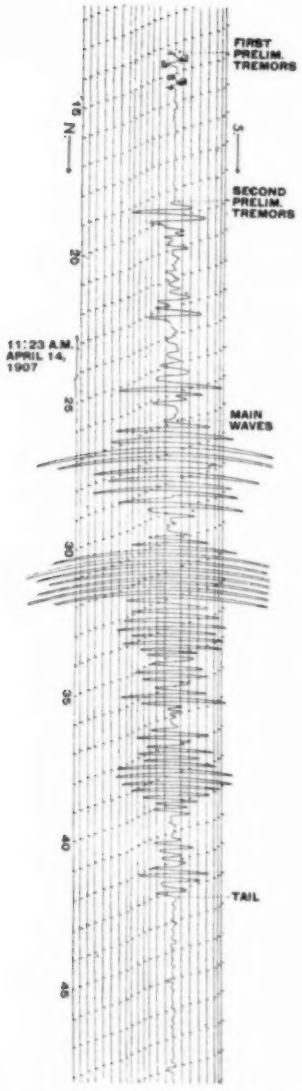


FIG. 1.—Record of the north-south component of the wave-motion rom the earthquake in Mexico of April 15, 1907, as registered on a Bosch-Omori horizontal pendulum at the U. S. Weather Bureau in Washington, D. C. (By courtesy of Professor C. F. Marvin.) The beginnings of the first and second preliminary tremors and of the main waves have been indicated. The intervals are minutes.

have an arcual path similar to, but deeper than, the "large waves," which follow them in time and are, as all agree, surface waves.[1] The velocity of these first waves, reckoned on this basis, would be about 14 kilometers per second instead of 10. Perhaps the strongest argument against this view is found in the known constants of surface rocks, which do not permit such a velocity. (See below, p. 400.)

It seems likely that the value assigned for the velocity of the direct waves may be subsequently considerably modified, since it has been largely based upon the records of the light Milne pendulums. Some sacrifice the pioneer must always make, and the standard Milne instrument suffers in comparison with the later German, Japanese, and Italian types, not only because of its lightness, but because the expense of photographic paper has necessitated a slow movement of the feeding-drum and a resulting contracted scale of the diagram. At the Batavia station a Milne and a Rebeur instrument have been installed side by side, and a comparison of the records now shows for the first time that the registration of shocks begins from one to ten minutes earlier upon the Rebeur pendulum.[2] The "preliminary tremors" of the Milne instrument may belong in the second phase of the records from more sensitive instruments.

For origins less than 1,000 kilometers distant such tremors do not appear in the seismogram, and it is supposed that they are combined with the large waves and reach the station at a speed of about 3.3 kilometers per second, with little doubt because of the lower rock densities which are traversed along the shorter and hence "crustal" chords.

The Earthquake Investigation Committee of Japan in 1894 instituted, at the suggestion of Professors Sekiya and Omori, a system of triangulation involving the use of four stations provided with exactly similar instruments and connected by telegraph to convey uniform ticks from a chromometer. The distances between the stations varied from 2.29 to 10.86 kilometers. All instruments being started by the same earthquake, the recognition of special marked vibrations

[1] Baron Dairoku Kikuchi, "Recent Seismological Investigations in Japan," *Pub. E.I. C.* (Foreign Languages), No. 19, 1904, p. 61.

[2] E. Rudolph, "Ostasiatischer Erdbebenkatalog" (1904), *Gerland's Beiträge zur Geophysik*, Vol. VIII, 1906 (1907), pp. 113–217.

allowed the times of arrival of the same shocks to be compared. The result obtained for the velocity of the surface waves of large amplitude (Section 5) was 3.3 kilometers per second, or the same as by the usual method.

It is a general observation that shocks are more violent at the earth's surface than they are in mines. At Przibram, in Bohemia, two similar modern Wiechert astatic pendulums have been installed, the one at the surface of the ground and the other in a mine 1,150 meters (or about 3,700 feet) under ground. The falling-off in amplitude of the shocks at the lower station is confirmed, but otherwise the seismograms appear to be nearly identical.

A most important study, and almost unique within its field, has been made by Nagaoka[1] upon the elastic constants of rocks. From his results he has obtained the velocity of propagation for waves in rock material, and these correspond fairly well with those actually measured by seismometers at the time of earthquakes.

The velocity of propagation of plane longitudinal waves within an infinite medium of steel is 6.2 kilometers per second. Within the earth's crust it is hardly to be expected that constant velocities will be obtained, since the crust is not homogeneous, and, further, is not isotropic, but quasi-crystalline. Several of the rocks investigated gave values for velocity as high as 6 and 7 kilometers per second. Nagaoka shows that a relation exists between the density and the elastic constant. In passing from Cenozoic to Archean rocks, with an increase of density from 2 to 3, the modulus of elasticity increased more than ten times in certain specimens. The mean earth density is 5.5+, and Nagaoka argues for a stratum of this density quite near to the surface. His studies have since been continued by Kusakabe,[2] using improved apparatus. For the velocity of propagation of waves in various types of Archean rocks Kusakabe

[1] H. Nagaoka, "Elastic Constants of Rocks and the Velocity of Seismic Waves," *Publications of the Earthquake Investigation Committee in Foreign Languages*, No. 4 (Tokyo, 1900), pp. 47–67.

[2] S. Kusakabe, "Modulus of Rigidity of Rocks and Hysteresis Function," *Journal of the College of Science*, Imperial University, Tokyo, Vol. XIX (1904), pp. 1–40, 22 plates and 53 figures. See also by the same author "A Kinetic Measurement of the Modulus of Elasticity for 158 Specimens of Rocks and a Note on the Relation between the Kinetic and Static Moduli," *Pub. E. I. C.* (Foreign Languages), No. 22 B, 1906, pp. 27–49.

obtained the average value 2.54. The average of all the rocks tested is a value slightly less than that of the large or surface earthquake waves.

The apparently uniform velocity of propagation of elastic earthquake waves through the core of the earth is a revelation of the first order of magnitude, for it indicates for the earth a uniformity of composition, and, moreover, a rigidity equal to one and a half times that of the hardest steel. The preliminary tremors from the great Indian earthquake of 1897, as received at Rocca di Papa, had an estimated period of 0.5 to 0.8 of a second, while their amplitude was but a fraction of a millimeter.

Following the preliminary tremors from a macroseism,[1] the seismogram indicates a second phase of larger disturbances; after which come the "large waves," which in the case of the quake above mentioned had a complete period of 22 seconds, a length of 34 miles, and a rise and fall of no less than 20 inches. These waves appear, therefore, to travel like a slow swell along the earth's surface.

Another fact of great interest is that the large waves gain in period of vibration and lose amplitude the farther they travel, so that an experienced observer can roughly estimate the distance of the disturbed area from the period of vibration of the waves. With fairly uniform rates of propagation established for both the direct and the surface waves which originate at any distant origin, the difference in time between the arrival of the preliminary tremors and that of the large waves gives a further measure of the distance of the origin from the observing-station. For example, a distance of 80 degrees corresponds to a time interval separating first preliminary tremors and first large waves of about 35 minutes.

Láska has derived surprisingly simple formulas for fixing the distance of the seat of disturbance in the case of remote earthquakes.[2] If V_1 be the time in minutes of the beginning of the preliminary

[1] Great confusion exists because of the different uses of the terms "macroseism" and "microseism," as well as of the adjectives derived from them. The usage here is that of both Milne and de Montessus, which makes "macroseism" apply to the greater disturbance on the ground.

[2] W. Láska, "Ueber der Berechnung von Fernbeben," *Mittheilungen der Erdbeben-Kommission der k. Akademie der Wissenschaften zu Wien*, N. F., No. 14 (1903), pp. 1–13.

tremors, V_2 that of the second preliminary phase,[1] and B that of the main or large waves in the seismograph; and if Δ be the distance in megameters (1 megameter equals 1,000 kilometers), then

$$1+\Delta=V_2-V_1$$

and

$$3\Delta=B-V_1.$$

Benndorf has proven by many determinations the correctness of these formulas,[2] which are known as "Láska's Rules," and which may be stated in simple form as follows:

1. *The duration of the first preliminary tremors in minutes, less one, is the distance of the seat of disturbance in megameters.*

2. *The duration of all preliminary vibrations in minutes, less one, is thrice the distance of the seat of disturbance in megameters.*

An illustration of the precision in the measurement of distance with unfelt quakes is given by Alfani, the director of the Ximeniana station at Florence, for the Indian earthquake of April, 1905,[3] the error in determining the distance being only 32 kilometers if the geographic center of the affected district be regarded as the starting-point of the shocks.

Omori, on the assumption that the velocity of the waves which produce the first preliminary tremors (over an arcual path) is 13.7 kilometers per second, and that the velocity of the second preliminary tremors is 7.2 kilometers per second, has deduced a formula for finding the time of occurrence of an earthquake from the observations at a distant station.[4]

His formula is

$$t_0 = t_1 - 1.165\, y_1$$

where t_0 is the time of occurrence of the earthquake, t_1 the commence-

[1] Laska finds that earthquakes less than 500 kilometers distant produce no second preliminary phase in the seismograph.

[2] H. Benndorf, "Ueber die Art der Fortpflanzung der Erdbebenwellen im Erdinnern," *Mitth. d. Erdbeben-Kom. d. k. Acad. d. Wiss. z. Wien*, N. F., No. 29 (1905), p. 19.

[3] P. G. Alfani, "Il terremoto d'India del 4 Aprile, 1905, e le registrazioni sismiche all' osservatorio Ximeniana di Firenze," *Rivista geografica Italiana*, Anno XII (1905), fasc. V, pp. 1–6.

[4] F. Omori, "On the Estimation of the Time of Occurrence at the Origin of a Distant Earthquake from the Duration of the First Preliminary Tremors Observed at Any Place," *Bull. E. I. C.*, Vol. I, No. 1 (1907), pp. 1–4.

ment time of the earthquake at the distant observing station, and y_1 the duration of the first preliminary tremors reckoned in seconds. The time is thus obtained through subtracting from the time when the record begins the duration in seconds of the first preliminary tremors after multiplying by the factor 1.165.

Careful analysis of earthquake records shows that the large waves may be further divided into four sections, designated the third, fourth, fifth, sixth, and sometimes additional sections of the seismogram (the two phases of the preliminary tremors being included in the numeration). The vibrations of the third section are few and slow, those of the fourth section are somewhat quicker and of very large amplitude, while those of section 5 are of much shorter period and of large amplitude. The durations of these different sections of the complete earthquake record are roughly equal to one another, the third and fourth sections being taken together. The amplitude is greatest in the fourth and fifth sections. The feeble vibrations which end the seismogram are called its "tail."

It has been rather generally held as a theoretic proposition that the direct waves which produce the preliminary tremors of the seismogram are longitudinal—that is, compressional—vibrations; whereas the "large" or "main" waves vibrate in the plane transverse to the line of propagation. A decisive experimental proof of the correctness of this view seems to have been happily furnished by the registration of the recent Kingston earthquake of January 14, 1907, by the seismograph of the U. S. Weather Bureau.[1] The two Borsch-Omori pendulums of the bureau are so placed as to record the north-south and the east-west components of the wave motion. Now it happens that the port at Kingston, which is something more than 1,400 miles distant from Washington, differs in longitude by only 15 minutes. For our purposes, therefore, Kingston may be considered as located upon the meridian of Washington. Practically *no preliminary tremors were registered in the east-west direction* at the time of the earthquake, though a very distinct series was recorded in the north-south direction. Notwithstanding this difference, the main waves appeared at practically the same instant in the two records, but

[1] C. F. Marvin, "The Kingston Earthquake," *Monthly Weather Review*, January 22, 1907, pp. 1–4.

the amplitude of the east-west component was about five times that of the north-south component.

The deep significance of these modern seismograms having been recognized, the necessity for co-ordinating the work of different observers at once became apparent; for, if the distance of an earthquake origin from three or more stations could be determined, its location could naturally be fixed with much greater precision and accuracy. Under the leadership of Milne, the British Association has secured the co-ordination of the work of some forty-five stations well distributed over the surface of the globe, where observations are made upon a uniform type of instrument. All reports are forwarded to a central committee of the association, which makes comparison, and once in six months issues a report that is mailed to all the stations for further study.

Japan, with its relatively small but widely extended territory, has at present, besides its *Central Meteorological Observatory* and the *Laboratory of the Seismological Institute of the Imperial University* (both at Tokyo), seventy-one local stations provided with seismographs, and 1,437 other stations scattered throughout Japan. The seventy-one stations of the higher class receive standard time by telegraph from the central station at Tokyo.

In Italy the *Central Office for Meteorology and Geodynamics*, directed by Professor Luigi Palazzo, co-ordinates the work of fifteen seismological stations of the first rank. For collecting information upon Italian earthquakes there are 150 regular correspondents well distributed through the peninsula and Sicily, and 650 other persons who have agreed to telegraph an immediate report to the central office when any earthquake shock has been perceived by them. Since 1895 the data thus collected have been regularly published in the *Bollettino della Società sismologica Italiana.*

Germany has established some twelve stations of the first rank, in addition to the head station at Strassburg, where may be found the highest development of instrumental refinement in earthquake study. Here have been held the international conferences upon earthquakes, and here was founded in 1903 the International Seismological Association. The organ of the association, the *Beiträge zur Geophysik*, is edited by Professor G. Gerland, the director of the station, from

which also the annual catalogue of seisms is regularly issued. The staff included Professors E. Rudolph, Dr. C. Mainke, and Mr. A. Sieberg, all highly trained seismologists. Germany is soon to inaugurate a system of co-ordinated distant stations, in which will be included Samoa, Kiao-chau, German East Africa, and the Bismarck Archipelago.

After Great Britain no nation has better opportunities for establishing a co-ordinated system of earthquake stations than the United States. Coming late into the field, it will not be required to make the sacrifices of the pioneer on account of earlier and cruder instruments, and its isolated outlying territory is admirably distributed for the purpose in view. With first-class stations and modern instruments at Washington, in New England, California, Alaska, Panama, Honolulu, Tutuila, Manila, Guam, Cuba, and Porto Rico, much might be accomplished to offset the minor rôle which the nation has thus far played in the great advance of seismology. At the last annual meeting of the American Association for the Advancement of Science, held in New York City in December, 1906, a committee of seismology composed of fifteen members was appointed, and at a meeting of this committee held in Washington almost upon the first anniversary of the great California earthquake, arrangements were made by which the United States Weather Bureau will make application to the next Congress for an appropriation to be used in inaugurating a co-ordinated series of earthquake stations well distributed throughout the country.

The great Indian earthquake of 1897 was the first macroseism upon the land to be studied both by co-ordinated distant stations and by geologists upon the ground.[1] The diagrams of the stations show that the waves traveled not only through but around the globe, thus furnishing a sort of parallel to the atmospheric wave started by the eruption of Krakatoa in 1883.

The seismograms of some earthquakes show more than one set of large waves, and these have been designated W_1, W_2, and W_3. The first mentioned appear to have reached the station by the nearest

[1] R. D. Oldham, "Report on the Great Earthquake of 12th June, 1897," *Memoirs of the Geological Survey of India*, Vol. XXIX (1899), chap. xv. The unfelt earthquake, pp. 227–56.

arcual route. The waves, W_2, are from the diminished amplitude, and the time of their arrival to be ascribed to vibrations transmitted in the opposite direction over the antipodes, while the waves W_3 are relatively feeble and the time of their arrival is about 3 hours, 31 minutes behind that of W_1, or that necessary for the waves of section 5 to make a complete circuit of the globe with a velocity of 3.3 kilometers per second. The seismogram of the Turkestan earthquake of August 2, 1902, indicates these waves W_2 and W_3 distinctly.[1] (see Plate IV).

Milne has recently drawn attention to the interesting fact that even in the case of lighter earthquakes, from which the energy is so dissipated that no record is obtained at the more distant stations, a distinct thickening of the lines from the pen of the instrument may be noted in the station located at the antipodes.[2] These "antipodean survivors" of the large waves in English home stations may be traced to earthquakes in New Zealand, and their survival at the antipodes only is to be ascribed to the cumulative effects of waves which converge from many great circle routes.

There is much that is yet only speculation regarding the nature of the waves registered by the new seismographs,[3] and some of the waves which have been indicated in the records of non-astatic pendulums have originated in the instruments themselves; but the value of the methods devised for locating the disturbed areas seems to have been established. This tendency of pendulums to vibrate in their natural period is now being corrected by automatic damping devices, with which a new epoch in the development of the science is opened.

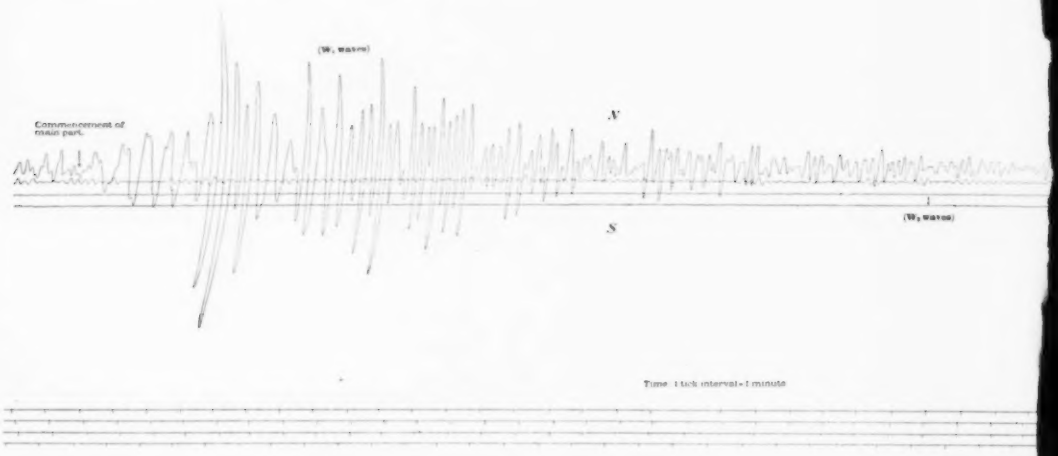
In his paper above cited Milne has brought together the results already obtained in the location of macroseisms.[4] On the basis of 265 such quakes recorded between 1899 and 1903, twelve seismic regions have been located which are either beneath the ocean or include both sea and continental border. (See Figs. 1 and 3 of

[1] Kikuchi, *loc. cit.*, p. 68, Fig. 37.

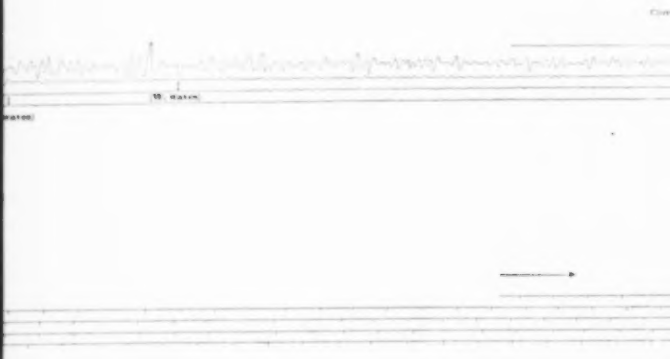
[2] John Milne, "Recent Advances in Seismology" (Bakerian lecture), *Proceedings of the Royal Society*, Vol. LXXVII (1906), p. 373.

[3] See W. Schlüter, "Schwingungsart und Weg der Erdbebenwellen," *Beiträge zur Geophysik*, Vol. V (1901), pp. 358, 359.

[4] A later report has been issued with 462 quakes included (Seismological Committee of the British Association for the Advancement of Science). See Fig. 2.

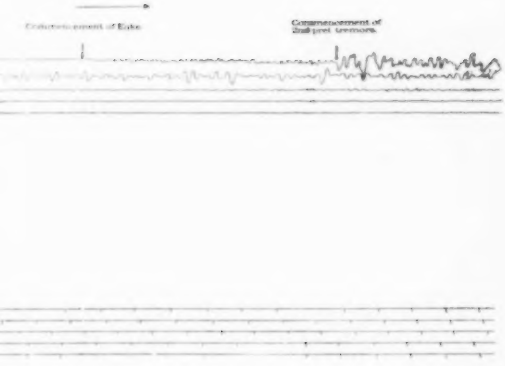


RECORD OF THE TURKESTAN EARTHQUAKE OF AUGUST



E OF AUGUST 22, 1902, OBSERVED IN TOKYO. (AFTER KIKUCHI)

Plate IV



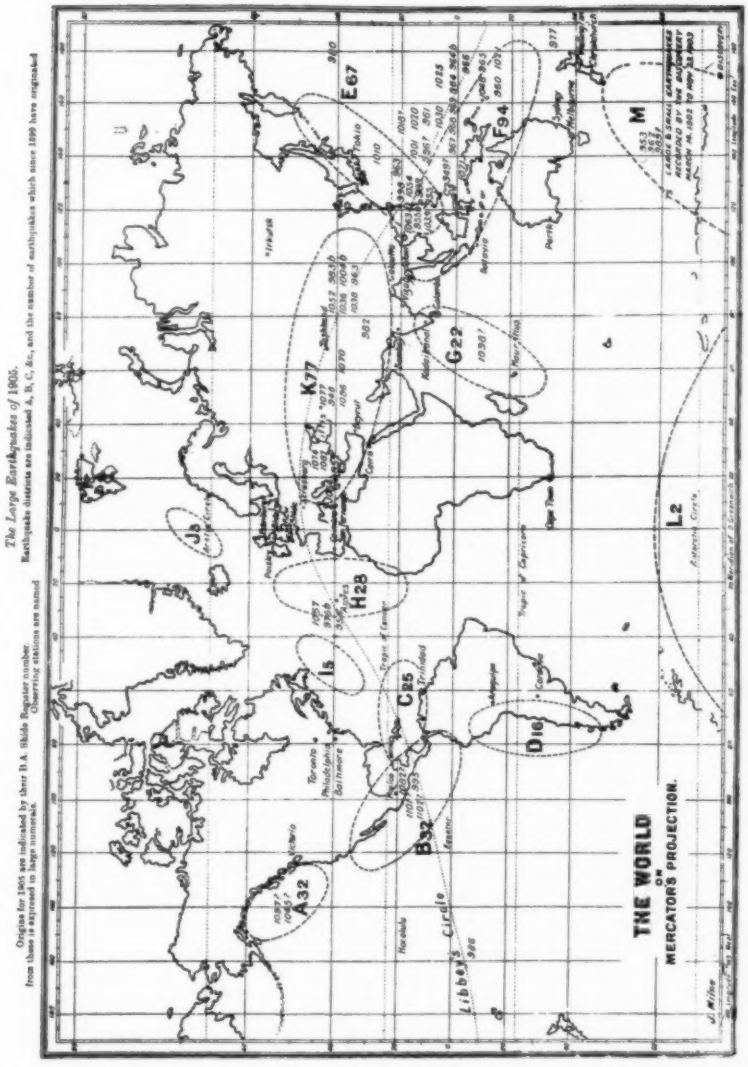


FIG. 2.—Map of earthquake "ovals," including the year 1905. (After Milne.)

the first paper of this series.) For the most part these are well-known earthquake regions, though the results have been criticized on the ground that certain well-known seismic regions, such as California, Andalusia, Lake Baikal, and New Zealand, are not indicated, while Newfoundland and the Indian Ocean are. As regards this objection, it should not be overlooked that regions of high seismicity may not necessarily be regions of equally frequent macroseisms, and the brief period that the method has been in operation removes much of the force of the objection so far as the seismic regions not indicated are concerned. As regards Newfoundland, the "oval" of Milne merely grazes its corner and is centered over the steep wall of the ocean deep at the margin of the Great Banks. As this scarp is off the lane of transatlantic steamers, direct observation of submarine quakes should in any case be seldom made. We find, however that on September 27, 1838, the ship "La Claudine," Captain Blount, while in this vicinity (Lat. 31° 40′ N. and Long. 42° 10′ W.) experienced a most severe series of shocks which lasted three-quarters of an hour. Occurring in the night and in perfectly clear weather, everyone was aroused and rushed on deck believing the ship was going down. Nearly all the breaks in the Atlantic cables occur at this wall, and on October 4, 1884, the three cables running here in parallel lines, about ten miles apart, were simultaneously fractured at points opposite each other and in a straight line.

The other oval of macroseismic origins to which objection has been made is likewise seldom crossed by vessels except at its margins, but we have here the record that on October 13, 1863, a submarine quaking of great intensity, accompanied by rumbling like thunder, was felt by a vessel in Lat. 20° S. and Long 67° E. Other severe quakes have been felt by vessels near the margin of this oval on February 9, 1823, and on January 29, 1882. It seems likely, therefore, that the new method is extending our knowledge of earthquakes into regions of which we should otherwise have at best but little knowledge, and it confirms the generalization that much the greater number of movements within the crust occur beneath the sea and at the borders of the great ocean deeps. A map based upon a larger series of observations is reproduced after Milne in Fig. 2.[1] Milne's

[1] British Association, *Seventy-sixth Report* (York, 1906), Plate I.

earlier map displays in addition the ridges and deeps of the ocean floor, and he shows that there is a relationship between the distribution of origins of macroseisms and the pronounced irregularities of the relief; thus affording for the sea areas a complementary verification of de Montessus' conclusions.

Editorial

The transfer of the United States Geological Survey from one administration to another is a matter of wide interest at any time, and is perhaps more than usually so at the present stage of official evolution in this country. The latter part of the administration of Major Powell and all of that of Dr. Walcott were conditioned by attempts to develop the related interests of irrigation, forestry, and so forth, and no small part of the time and strength of these administrations was given to enterprises very worthy in themselves, but not strictly geological. The Survey will have contributed much to the general good of the country by aiding in putting these related interests under scientific control, but, in the judgment of many geologists, the Survey itself has temporarily suffered in consequence, scientifically and probably financially. In the closing stages of Dr. Walcott's administration the chief of these annexations to the Survey were separated from it and the way prepared for a more strictly geological administration. Some further limitations may be wholesome, but the new administration under Dr. Smith inherits an excellent opportunity to show what can be done by an undivided devotion to the development of strictly geological work in the interest of industry, education, and science.

Just at present the attention of the country is specially alert to the future relations of federal and state functions, and this adds piquancy to the problem of the relations of the national to the state surveys. It is a hopeful sign that steps have already been taken to adjust these relations in a more satisfactory way. More fundamental than the formal relations of the national to the state surveys is the question of true interstate work with a view to general correlation and fundamental science, in contradistinction to essentially local work of an intra-state nature.

Of similar import is the question of the relations of the national survey to the institutions which produce its working talent. Of like importance is the obligation of the Survey to develop the talent it

employs by continuous work in broad, unrestricted fields, until real mastery is attained. Even more imperative is adequate provision for the close scientific oversight of each chief line of work by commanding talent, developed by a far-seeing and steadfast policy in the interests of the highest class of work.

These are only some of the large outstanding problems that give a rare opportunity to the new administration. In the solution of these, as also in the more mechanical as well as the more diplomatic problems of the Survey, Dr. Smith will have the cordial good wishes of geologists generally, and, beyond question, their help, if he chooses to draw about himself the united talent of the country.

T. C. C.

Geological surveys have recently been established in Arkansas and Colorado by the action of the legislatures of those states. Notable additions have also been made to the financial resources of the surveys of Illinois, Missouri, and Iowa. Some further favorable action is expected from legislatures still in session. In line with this there has recently been a notable increase in the facilities for geological instruction given in several of the higher institutions of learning in the same region. These correlative actions appear to indicate a marked growth of geological interest in the interior states. Co-operation between the state surveys mutually, and between these and the higher institutions of learning, has grown co-ordinately, and is a hopeful sign of further growth and strength in the future.

T. C. C.

Reviews

Maryland Geological Survey—Pliocene and Pleistocene. William Bullock Clark, State Geologist, 1906. Pp. 285, 13 figs., 75 plates.

This is the third volume of a series of reports dealing with the systematic geology and paleontology of Maryland. It consists of two parts; the first, devoted to the Pliocene and Pleistocene deposits of Maryland, by G. B. Shattuck, with interpretations of the paleontological criteria by W. B. Clark, Arthur Hollick, and F. A. Lucas; the second, to the systematic paleontology of the Pleistocene, by Clarke, Lucas, Hay, Hollick, Sellards, and Ulrich. The report appears in the handsome dress for which the Maryland reports have become noted, and its many and excellent illustrations give it an attractive appearance.

The chief geological contribution is Dr. Shattuck's report of 136 pages. Besides introductory matter, this treats of four formations: the Lafayette, regarded as Pliocene, and the Sunderland, Wicomico, and Talbot, regarded as Pleistocene. The last three are relatively new terms introduced by Dr. Shattuck to designate the Pleistocene formations which he discriminates. They cover in a general way about the range of deposits embraced under the Columbia of McGee. All these formations, including the Lafayette, are regarded as sea deposits, in the main, and maps are given showing the supposed extent of the Lafayette, Sunderland, Wicomico, and Talbot seas. The formations are conceived to constitute a succession of terraces which are said to be limited by sea-cliffs. The assigned relations of these terraces are made clear by a series of ideal diagrams. There is a notable similarity in the structure and constitution of these formations as indicated by the descriptions and the photographs, all consisting mainly of clay, loam, sand, and gravel, with iron ore and other segregations. A significant feature is the imperfect assortment and the irregular arrangement of the material, which affects particularly the upper parts of the formations.

The surface movements supposed to be involved in the formation of this series of deposits are summarized as follows:

Subsidence and deposition of the Lafayette formation.
Elevation and erosion.
Subsidence and deposition of the Sunderland formation.

Elevation and erosion.
Subsidence and deposition of the Wicomico formation.
Elevation and erosion.
Subsidence and deposition of the Talbot formation.
Elevation and erosion.
Partial subsidence and deposition of the recent terrace.

Dr. Shattuck closes his report with the remark that "a study of the Coastal Plain deposits from the bottom to the top shows that the Atlantic sea-board has been repeatedly elevated when loaded and depressed when lightened. It would seem that some other theory than that of isostasy must be proposed for these movements" (p. 137).

Under the head of interpretation of the paleontological criteria, Dr. Clark remarks that all the fossils come from the Pleistocene, none from the Pliocene, i. e., the Lafayette. Fossil plants are found in all three of the Pleistocene formations—though imperfect in Wicomico—but the animal remains are confined to the latest or Talbot formation. In addition to the marine fossils in the Talbot formation, leaves, seeds, fruits, twigs, branches, logs, and stumps are preserved, some of which, according to Dr. Hollick, represent the accumulation of vegetation in place, in swamps, lagoons, or estuaries, and some represent transportation from adjacent localities. A few mastodons' teeth and other vertebrate remains have been found in the Talbot formation.

One cannot quite agree with Dr. Clark in saying that "the evidence of the fossils, as far as available, bears out the conclusions" previously set forth (p. 139), if by that is meant the marine origin of the Sunderland and Lafayette formations, as one would infer. The occurrence of marine fossils in some parts of the Talbot formation, the lowland, sea-border member of the Pleistocene deposits, rising from 10 to 45 feet above sea-level, while land vertebrates and plants are found in other portions, implies that the deposit was formed partly under marine conditions and partly under terrestrial.

The occurrence of a score of species of land plants and the absence of marine fossils in the Sunderland formation, which lies at higher levels, point as distinctly, so far as the evidence goes, to the terrestrial deposition of that formation. The absence of fossils in the Lafayette of Maryland, and the presence of land fossils in the Lafayette elsewhere, point in the same direction.

Concordantly with the fossil evidence, geologists critically familiar with the distinctions between marine and terrestrial formations will be disposed to question the marine character of such kinds of assortment and such

structures as are shown in the several excellent photographs of sections of the upland formations. This questioning would be more pointed, if the chemical and physical state of these deposits had been more critically described. Question will also arise whether the little bluffs called sea-cliffs are really such. They look much like the terrace edges cut by low-gradient drainage. The digitate borders of the formations as mapped on Plate I, and on the restorations of the sea limits of the several stages as mapped on Plates XXVII–XXX, present strange alignments for the putative shores of the Atlantic. The little off-shore islands of soft material seem equally strange features. So also one looks in vain for the great sand-bars and strong beach deposits that are usually associated with ocean borders. If critical inquiry is turned to the elevations of the several parts of the upland formations, there appears to be a closer resemblance to the habitual hypsometry of terrestrial formations than to that of marine. One does not find in the report evidence of a clear perception of the methods of terrestrial deposition, such as are applicable to a region of this kind, and one is left with the suggestion that, when the region is critically studied with terrestrial criteria sharply in mind, the upland formations will be found to be typical terrestrial deposits, as implied by the fossil evidence. A part of the lowland Pleistocene is undoubtedly marine.

The systematic treatment of the paleontology of the Pleistocene deposits is an admirable feature, and will prove very serviceable in the study of the Pleistocene formations of the coast both to the southward and to the northward where warmer and colder faunas, respectively, were prevalent.

T. C. C.